International Library of Technology
305

Radio
Devices and Communication

231 Illustrations

Prepared Under Supervision of

FRANCIS H. DOANE, A. M. B.

DIRECTOR, ELECTRICAL SCHOOLS, INTERNATIONAL CORRESPONDENCE SCHOOLS

ELECTRICITY AND MAGNETISM
GENERATION OF ELECTROMOTIVE FORCE
CODES AND CODE PRACTICE
RADIO DEVICES
DAMPED-WAVE RADIO TELEGRAPHY
ELECTRON TUBES
UNDAMPED-WAVE RADIO COMMUNICATION

Published by
INTERNATIONAL TEXTBOOK COMPANY
SCRANTON, PA.
1925

Printed in U. S. A.

PRESS OF
INTERNATIONAL TEXTBOOK COMPANY
SCRANTON, PA.

305 87788

PREFACE

The volumes of the International Library of Technology are made up of Instruction Papers, or Sections, comprising the various courses of instruction for students of the International Correspondence Schools. The original manuscripts are prepared by persons thoroughly qualified both technically and by experience to write with authority, and in many cases they are regularly employed elsewhere in practical work as experts. The manuscripts are then carefully edited to make them suitable for correspondence instruction. The Instruction Papers are written clearly and in the simplest language possible, so as to make them readily understood by all students. Necessary technical expressions are clearly explained when introduced.

The great majority of our students wish to prepare themselves for advancement in their vocations or to qualify for more congenial occupations. Usually they are employed and able to devote only a few hours a day to study. Therefore every effort must be made to give them practical and accurate information in clear and concise form and to make this information include all of the essentials but none of the nonessentials. To make the text clear, illustrations are used freely. These illustrations are especially made by our own Illustrating Department in order to adapt them fully to the requirements of the text.

In the table of contents that immediately follows are given the titles of the Sections included in this volume, and under each title are listed the main topics discussed. At the end of the volume will be found a complete index, so that any subject treated can be quickly found.

INTERNATIONAL TEXTBOOK COMPANY

CONTENTS

ELECTRICITY AND MAGNETISM

ELECTRICITY

SOURCES OF ELECTRIC PRESSURE

1. Manifestations of Electricity.—Broadly defined, **electricity** is the cause of all electrical phenomena or manifestations. As is the case with gravity, the exact nature of electricity is not known, but the general characteristics and many laws governing its actions are well understood. Electricity may then be studied by the effects that it produces.

Common evidences and results of electricity are: (1) lightning; (2) heat due to the flow of electricity through a body; (3) attraction of light bits of paper by a glass rod rubbed with silk; and (4) violent agitation of the nervous system of all animals which is called a shock.

2. Electric Charges.—An **electric charge** is an accumulation of *static electricity*. **Static electricity,** or electricity at rest, resides on the surface of bodies as a charge. In distinction from static electricity, electricity in motion, manifested as electric currents, may be called **dynamic electricity.**

3. When a glass rod is electrified by rubbing it with silk, the charge resides on any of the parts rubbed, and disappears almost instantly if these parts are touched with anything through which electricity can pass. Also the charge gradually creeps along the surface of the glass rod. An *electric pressure* is established that, under certain conditions, will cause a flow of electricity or cause movements of light bodies placed near

the glass rod or piece of silk. The same statements are true of charges established in any other way, as by rubbing wax with flannel or by the friction of a leather belt on an iron pulley. Any insulated body may have an electric charge accumulated on its surface, either by friction or by transfer from some charged body.

4. When an electrified glass rod is held near an insulated piece of light material, as a pith ball, Fig. 1, the material will be attracted; if allowed to touch the glass, the ball will promptly swing away from it and will recede whenever the glass is brought near. If another pith ball is treated in the same way, the two balls will repel each other. Sealing wax electrified by rubbing it with flannel will attract light pieces that have been repelled by the charge on the glass that has been rubbed with silk. For example, if the electrified wax is brought near the pith ball, Fig. 1, that has been charged and repelled by the glass, the ball will be attracted to the wax. The charge on the wax is therefore unlike that on the glass, as it attracts the charged pith ball which was repelled by the glass rod.

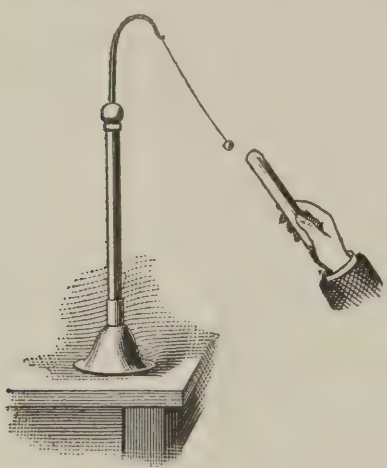


Fig. 1

5. Two kinds of electric charges, or of static electricity, are thus illustrated. The names *positive* and *negative* are used to designate these charges. Neither can be developed without the other. The charge developed on glass when it is rubbed with silk is positive, and an equal negative charge is at the same time developed on the silk. A negative charge is developed on sealing wax when it is rubbed with flannel, and an equal positive charge is simultaneously developed on the flannel. Combining a positive charge with an equal negative charge neutralizes the effect of each.

6. Electrostatic Laws.—Electric charges act according to the following laws:

1. When two dissimilar unelectrified substances are brought into contact, one assumes a positive and the other a negative condition.

2. An unelectrified body on coming into contact with an electrified body becomes electrified with a charge similar to that on the electrified body.

3. Similarly charged bodies repel each other; dissimilarly charged bodies attract each other.

7. Electric Pressure by Chemical Action.—A **primary cell** is a combination of materials in which chemical action establishes an electric pressure, also called an *electromotive force,* or *voltage,* between parts of the cell as soon as the materials are properly combined. When two plates, one zinc and the other copper, are partly immersed in dilute sulphuric acid, as shown in Fig. 2, chemical action is set up within the cell, the acid attacking the zinc and gradually eating it away. Under such conditions, electromotive force is established between the plates, and electricity flows through the wire that connects the plates.

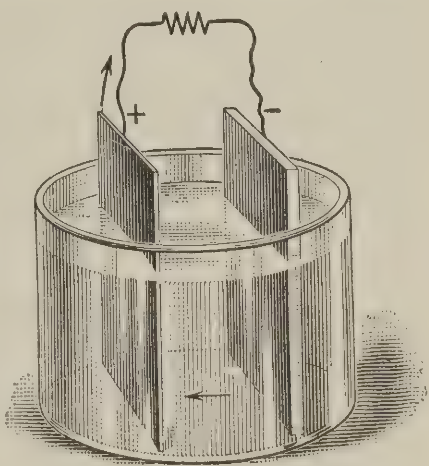


FIG. 2

8. Other metals than zinc and copper and other liquids than dilute sulphuric acid may be used; in general, when any two dissimilar metals are placed in a solution that attacks one of them, an electromotive force is established between the two plates. The liquid within the cell is usually called the *electrolyte,* irrespective of the chemicals which may be used.

Whatever the nature of the plates, they are called **electrodes,** and the terminals, or ends, of these electrodes, to which the connecting wires are attached, are called the **poles** of the cell. The common conception is that electricity always flows through the wire outside of the cell, from the plate or electrode that is not consumed to the plate that is consumed.

The terminal attached to the copper electrode is therefore called the *positive terminal,* and the terminal attached to the zinc electrode is called the *negative terminal.*

A more complete description of cells will be given in a later Section. For the time being they are important as one common source of electromotive force.

FIG. 3

9. In electrical diagrams it is convenient to employ simple symbols for the various pieces of apparatus so as to save time and space in drawing and to avoid confusion. The symbol of an electric cell is a pair of parallel lines, one long and thin, representing the positive pole, the other shorter and usually thicker, representing the negative pole. A **battery,** which is a combination of two or more cells connected together, is shown by this symbolic representation in Fig. 3.

ELECTRIC CURRENTS

10. An **electric current** is a flow of electricity, and this flow is assumed to have direction. An electric current is established by an **electromotive force** (often written e. m. f.), which may be compared to the pressure causing a flow of water in a pipe. The flow of electricity, or the electric current, in a given wire depends on the electromotive force causing it, just as the rate at which water flows through a pipe depends on the pressure forcing it through.

11. The **direction of flow** of electricity is not definitely known. For convenience it has been agreed that the electrical condition called positive represents a higher electromotive force than that called negative, and that electricity tends to flow from a positively to a negatively electrified body. Positive and negative are represented by the signs + and − respectively, and electricity is said to flow from + to −, a fact which was mentioned in a preceding article describing the primary cell.

12. Electric currents are of two general classes, *direct current* and *alternating current,* these names being to a large extent

descriptive of the chief characteristic of the class to which each applies.

13. A **direct current** is a flow of electricity always in the same direction. The current produced by an electric battery is a common example of this kind of current.

A direct current may vary from time to time, in which case it is a *fluctuating*, or *variable*, direct current; but a direct current of unchanging strength, such as that from a battery in a circuit which remains constant, is known as a *steady*, or *continuous*, current. If a direct current is made to vary in a certain manner, being weakened and strengthened at regularly recurring intervals, it is called a *pulsating* current.

14. An **alternating current** is a flow of electricity that reverses in direction, the reversals usually occurring with such great rapidity that the eye can detect no change in the brilliancy of electric lamps lighted by such current. Two such reversals, or *alternations*, of the current constitute a *cycle*. The **frequency** of an alternating current is usually expressed as the number of cycles per second. The frequency may be constant, as is the case with alternating current employed for light and power; or it may be variable, as is the case with currents used in electrical transmission of speech. Currents with variable frequency reverse at irregular intervals.

ELECTRIC CIRCUITS

CONDUCTORS AND INSULATORS

15. A good **conductor** of electricity is a substance that will offer very little opposition to the flow of electricity through it. Materials vary considerably in their ability to conduct electricity, some being very much better conductors than others.

Among such materials, arranged in order with the best conducting material first, are silver, copper, gold, aluminum, zinc, brass, phosphor-bronze, platinum, tin, nickel, lead, German

silver, steel, iron, mercury, carbon, and water. Silver and gold are too expensive to be generally used for electric conductors. Copper, being plentiful and comparatively cheap, is in very general use, and aluminum is also much employed, particularly where light weight is required.

16. An **insulator** is a non-conductor which offers so much opposition to the flow of electricity that practically no current can get through it. Among the best known insulating materials are glass, porcelain, rubber, mica, ebonite, dry paraffined wood, paper, vulcanized fiber, asbestos, pure asphalt, air, and oils. Insulators are used to support conductors and to keep the electricity confined to the wires intended for it. For example, telegraph, telephone, and electric-light wires on poles are fastened to glass or porcelain insulators.

It is important to remember that as all materials conduct electricity to a certain extent, it is impossible to divide them absolutely into groups of conductors and insulators; but for practical purposes they may be so divided, as the resistance of a good insulator is several million times that of a good conductor.

CLASSIFICATION OF CIRCUITS

17. An **electric circuit** is a conductor, or a series of conductors, through which electricity may flow. Such a circuit is **closed, completed,** or **made,** when it is continuous so that electricity may flow from a given point around the whole path and back to the starting point. The circuit is **broken,** or **open,** when it forms an incomplete path, effectually preventing a flow of electricity. The circuit may also include any electrical devices through which electricity will flow.

The **external circuit** is the part of the circuit outside of the source of electromotive force, or external to it; the **internal circuit** is the portion within the source of electromotive force. In the case of the cell shown in Fig. 2, the external circuit is the conductor connecting the terminals of the plates, while the internal circuit consists of the two plates and the electrolyte.

18. An electric circuit is said to be **grounded** when any part of it is in electrical connection with the earth or with a conductor leading to the earth. Although the resistance of a small section of earth is rather high, the very large amount of

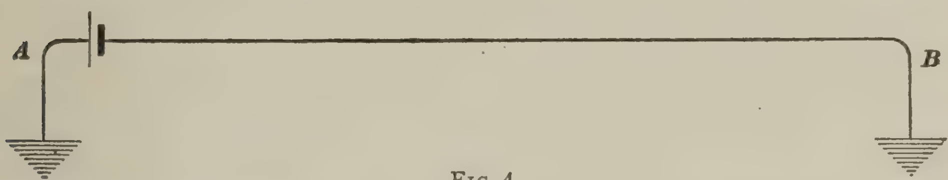


FIG. 4

it between any distant points renders the resistance between those points rather low. The earth may act as a vast conductor and actually does form a part of many electric circuits, particularly in telegraph practice. Fig. 4 illustrates such a condition with a circuit, including a battery, connected between points A and B. The diagrammatic symbol for an earth, or ground, connection is shown just below points A and B, and the *ground return* for the current is through the earth from A to B.

In distinction from a ground-return circuit, one formed entirely of metal conductors, as indicated by Fig. 5, is a **metallic circuit.** Electricity flows from A through the

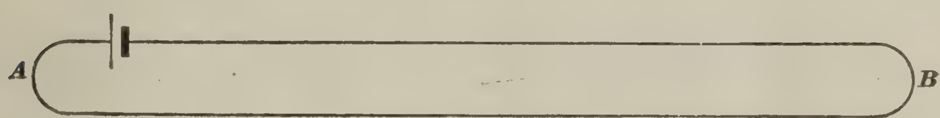


FIG. 5

lower part of the circuit to B, and then returns through the upper portion of the circuit and battery to A. By far the larger number of electric circuits are metallic, as operating conditions and the transfer of electric energy are then at their best.

ELECTRIC RESISTANCE

19. Electric resistance is opposition to the flow of electricity. In general, conductors have low resistance and nonconductors have comparatively high resistance. No known substance is wholly without resistance. The resistance of a conductor depends on its size and the material of which it is

made. If a water pipe is small, it will restrict the flow of water under a given pressure. If the pipe is rough on the inside, it will also restrict the flow. On the other hand, a large, smooth pipe will offer a better path and less resistance to the flow of water. Applying this same thought to an electrical conductor, such as a wire, a small wire tends to restrict, or resist, the flow of electricity to a greater degree than a large wire of the same metal. Also, materials such as copper and silver restrict, or resist, the flow of electricity less than other metals, such as iron. The resistance of a conductor is a quality of the conductor itself and not of the electricity flowing in it or of the electromotive force causing the flow.

There are many cases arising in practice in which it is necessary to use a device possessing considerable resistance. Often the purpose is to decrease the voltage of the source of current so that a lesser voltage may be applied to the terminals of another piece of apparatus. When a resistance device is connected in circuit with a piece of apparatus, the voltage across the terminals of the apparatus will be lower than if the resistance device were omitted. The difference in these values is equal to the voltage that is required to force current through the resistance device.

In such a case it is desirable that the conductor of the resistance device, which is usually in the shape of a wire, should possess a fair amount of resistance, so the device will not be too bulky. While the wire for such devices is always in the class of conductors, it is a very poor one, the better to serve its purpose. Alloys, or combinations of several metals, are ordinarily used in this work, although iron wire or even long lengths of cast iron are used in many electrical installations. The conductor is usually wound or assembled on an insulating support of some kind and may afterwards be covered with an insulating and heat-conducting material. This protective coating of paint or other insulating preparation prevents decomposition of the resistance material, as well as accidental contact with the live conductors.

SERIES GROUPING

20. Electric conductors, sources of electromotive force, or devices using electricity may be connected in several ways. A **series** circuit is formed when the connections of its parts are such as to provide only one continuous path for the flow of electricity. All the electricity must pass through each conductor, making the current equal in each of the conductors. For example, Fig. 6 represents a closed series circuit from cell *B* through $c–r_1–e–r_2–d$ and through cell *B*. The cell, conductors, and resistances are in series, because they are in one path; the same current exists in all of them, and its direction is indicated by the arrows.

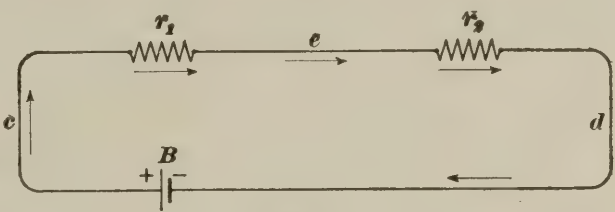


Fig. 6

Fig. 6 serves to show the usual, or conventional, method of representing resistances, which is by the sharp-pointed wavy line as shown at r_1 and r_2. The resistance of several conductors or resistances connected in series is equal to the sum of the resistances of the conductors and resistance devices.

21. Sources of electromotive force are connected in series when their terminals are joined so that the voltages are added. Fig. 7 represents six electric cells connected in series; the positive terminal of each cell is joined with the negative terminal of the next cell in the series. The circuit is represented open, and the arrows show the direction of electromotive force, or the direction in which electricity would flow if the circuit were closed. If the external circuit consists of a continuous path, the total electromotive force acting in the series circuit will be the sum of the electromotive forces of all the six cells.

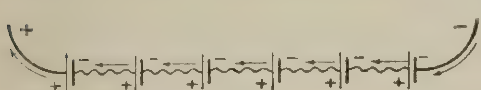


Fig. 7

PARALLEL GROUPING

22. Conductors are connected in **parallel,** or **multiple,** when so joined that each will carry part of the total current in the circuit of which they are branches. Fig. 8 shows a closed circuit consisting of a source of electromotive force *B,* and conductors *a, b, c,* and *d.* Conductors *b* and *c* afford two current paths between conductors *a* and *d,* and are therefore in parallel. Either path *b* or *c* could be broken without interfering with the flow of electricity through the remaining path, because each is independent of the other. The arrows indicate the direction of the current with normal circuit conditions.

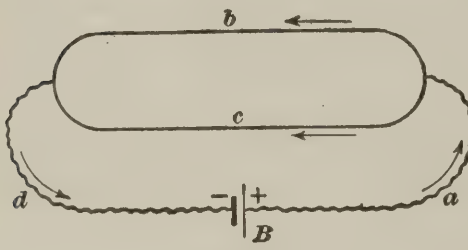


FIG. 8

Each branch is a *shunt* of the other, or *in shunt* with it, and the two together form a *divided circuit.* A circuit shunted by a low-resistance conductor is said to be *short-circuited* by it, and the shunt in such case may be called a *short circuit,* or simply a *short.*

23. Resistance of Similar Conductors in Parallel Groups.—In Fig. 8, the two paths *b* and *c* together are larger, and hence lower in resistance, than either path would be alone. Joining in parallel two conductors of the same material and of the same size and length is equivalent to making one conductor twice as large as either one of the two joined, and doubling the size of the conductor divides its resistance by two. As the number and values of the parallel paths change, the solution of such problems becomes much more difficult.

24. Sources of electromotive force are connected in parallel, or multiple, when all their positive terminals are joined to one conductor and all their negative terminals to another conductor, as in Fig. 9. The electromotive force

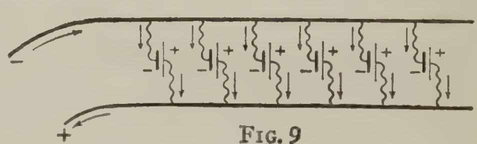


FIG. 9

between the two conductors is the same as that of any one of the equal sources. The arrows indicate the directions of the electromotive forces, or the direction in which electricity would flow if the external circuit were closed. The current in the external circuit would then be equal to the sum of all the currents from the several sources of electromotive force. For example, if the six sources of electromotive force indicated in Fig. 9 were equal, and if the current through each source were 2 amperes, the current in the external circuit, when closed, would be 12 amperes.

PARALLEL-SERIES AND SERIES-PARALLEL GROUPINGS

25. When electrical devices are connected in several series and these series are connected in parallel, as in Fig. 10, the devices are said to be connected in **parallel-series,** or **multiple-series.** If the devices are electric cells, as indicated, each series should contain the same number of similar cells; the positive terminals of all the series are connected to one conductor and the negative terminals to the other.

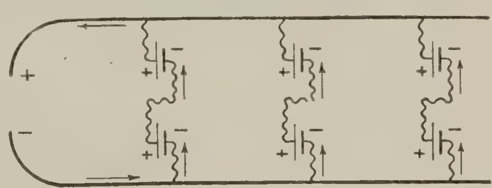


FIG. 10

The electromotive force between the two conductors is the same as that of any equal series, and if the external circuit were closed, the current would be the sum of the currents in all the series.

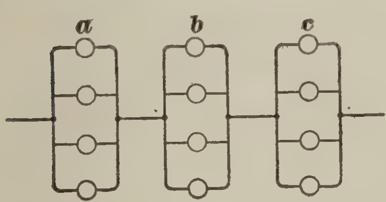


FIG. 11

26. Series-parallel connection means literally a *series of parallels,* as indicated in Fig. 11, in which three groups *a, b,* and *c* are connected in series, each group having four devices in parallel.

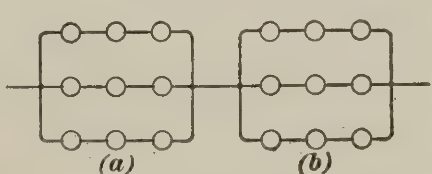


FIG. 12

The expressions *parallel-series* and *series-parallel* are frequently used without distinction as to meaning, and the distinction is not usually of great importance in practice. Circuits

including both methods of connection are sometimes used, as in Fig. 12, in which each part (*a*) and (*b*) is a parallel-series connection and the two parts connected in series form part of a series-parallel circuit.

ELECTRICAL UNITS AND MEASURING DEVICES

QUANTITY OF ELECTRICITY

27. Coulomb.—Electricity is measured by its effects, or the work it does; the greater the effect, or the work done, the greater is the quantity of electricity. When it flows through the electrolyte of an electric cell, for example, some of the liquid is decomposed into gases, and the greater the quantity of electricity, the larger is the formation of the gases. When electricity is caused to flow through an electrolyte containing a metal in solution, some of the metal is deposited on one of the electrodes, the amount being proportional to the quantity of electricity.

The **coulomb** *is the unit quantity of electricity,* and is the quantity that deposits a certain amount (.01725 grain) of metallic silver from a carefully prepared electrolyte containing silver dissolved in nitric acid. This statement is true regardless of the time required for making the deposit.

CURRENT

28. Ampere.—The **ampere** (abbreviated amp.) *is the practical unit rate of flow of electricity,* or *unit current,* and is the rate when 1 coulomb flows each second; that is, *amperes equal coulombs per second.* The value, or strength, of an electric current is practically always expressed in amperes. This unit expresses the flow of a definite quantity of electricity per second. One *milliampere* is $\frac{1}{1000}$ ampere; 1,000 milliamperes equal 1 ampere.

AMMETERS

29. Ammeter for Power Circuit.—In practical work, electric current is measured by means of an instrument called an **ammeter,** of which Fig. 13 shows one type commonly used in lighting and power circuits. The ammeter is connected in series in the circuit by inserting the ends of conductors in the openings in the two binding posts and clamping them with the thumbscrews at the tops of the posts. The current in the circuit causes the pointer to deflect over the scale to a figure indicating the strength of current in amperes or milliamperes.

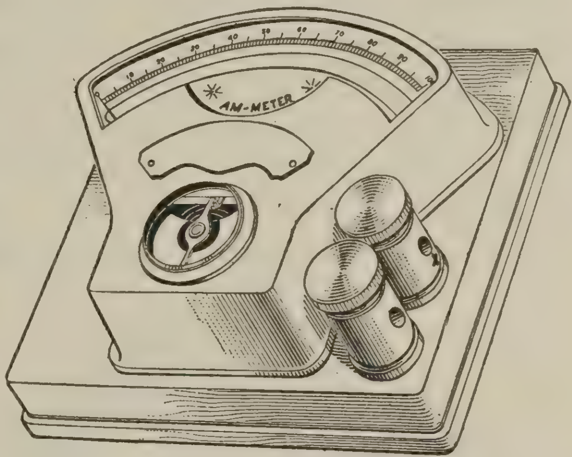


FIG. 13

30. Ammeter for Radio Circuits.—Ammeters of the **expansion type,** or, as sometimes called, of the *hot-wire type,* are often used for measuring current in radio circuits. The action of the instrument is based on the heating effect of a current in a conductor, and the change of length of the conductor with its change of temperature. The heat developed in a given conductor is proportional to the square of the current, and the length of the conductor increases or decreases with an increase or decrease of the temperature. The square of a number is the product obtained by multiplying the number by itself. For example, the square of 4 is 16, or 4 multiplied by 4 equals 16; or the square of 25 is 25 multiplied by 25 equals 625.

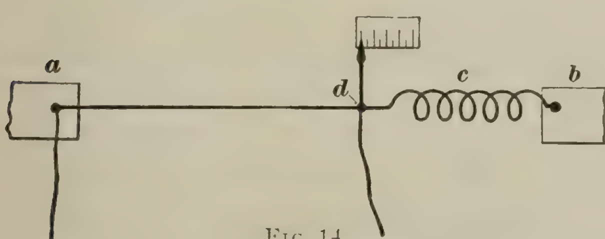


FIG. 14

Fig. 14 shows the principle of such instruments. The wire by means of which the current is to be measured is kept taut between two fixed points *a* and *b* by spring *c*; a pointer attached to the wires at *d* moves over a scale marked so as to indicate the current being measured. An increase of the current in the wire causes the wire to lengthen, the spring takes up the slack, and the pointer moves along the scale toward the right. With a steady current, the pointer comes to rest at some point and a reading may be taken. If the current decreases, the wire contracts and the pointer is moved toward the left to a new position. In commercial instruments, means are provided so that a slight change in the length of the conductor causes a considerable change in the position of the pointer.

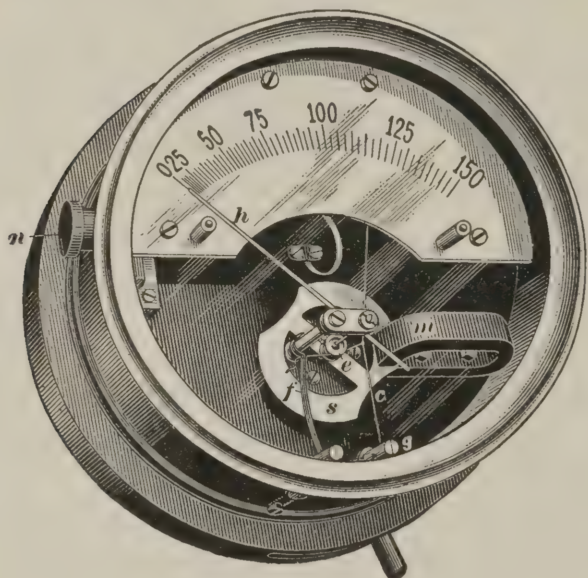


Fig. 15

Instruments of the expansion type are made for measuring current or voltage on either direct-current or alternating-current circuits. An external shunt is used with a switchboard ammeter above 5-ampere capacity and an internal resistance for voltmeters reading up to 150 volts.

31. Fig. 15 shows the exterior of an expansion ammeter, and Fig. 16, the working parts. The parts shown in both figures are indicated by the same reference letters. Current in the wire *a b*, Fig. 16, heats it and causes it to expand. To eliminate errors due to changes in room temperature, the wire is supported on a base that expands or contracts at the same rate as the wire when both are subjected only to room temperature. At a point on the wire *a b* a second wire *c* is attached. The

other end of wire *c* is fixed to post *g*. To this second wire is attached a very fine wire *d*, which passes around the small pulley *e* and is held taut by the flat spring *f*. The pulley is mounted on a vertical shaft, which also carries the pointer *h* and the aluminum damping disk *s*. The shaft is mounted on jewel bearings so as to turn with the least amount of friction.

The wire *a b* is stretched taut when not heated and a very small expansion causes a considerable sag. The spring *f* takes up the sag in wires *a b* and *c* and as wire *d* is wound on a pul-

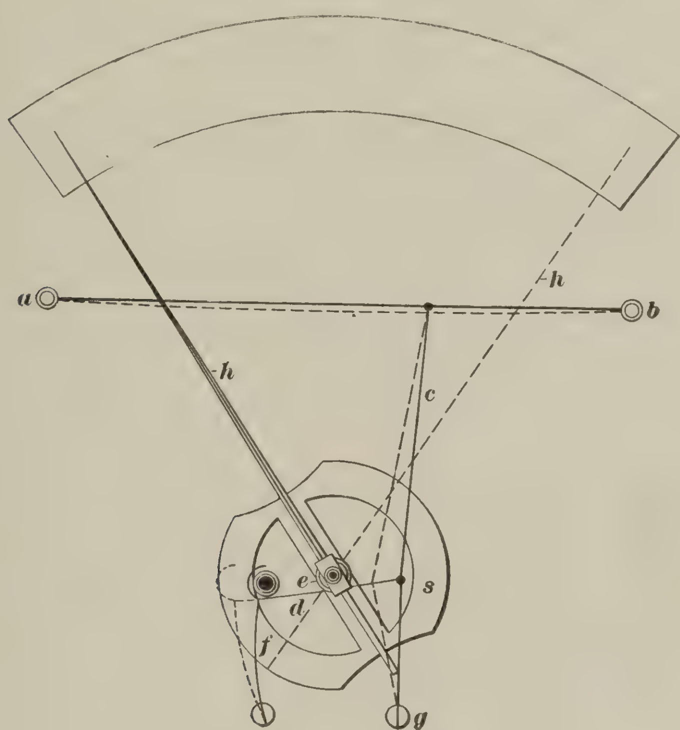


Fig. 16

ley *e*, any increase or decrease of sag causes a movement of the pointer. The pointer moves to a position on the scale corresponding to the current passing through the instrument. The dotted lines show, in an exaggerated way, the stretched positions of wires *a b* and *c*.

32. The knob *n*, Fig. 15, serves to adjust the pointer at the zero mark by slightly varying the position of the post *a*, Fig. 16. The movements of the needle are damped by means of the aluminum disk *s*, a portion of which turns between the poles of

the permanent magnet m, Fig. 15. This action is due to magnetic attraction between the stationary magnet and the current established in the moving disk. The explanation of this principle as applied to generators is given in another Section. The pointer being damped travels steadily over the scale until a correct reading is indicated, and then comes to rest promptly. Were it not damped, the pointer would be apt to vibrate several times, thus causing delay in obtaining a measurement. The handle near the bottom of the case, Fig. 15, operates a switch so that the instrument circuit can be opened when no readings are desired. However, this refinement is not commonly provided in this type of instrument.

33. When the instrument is used to measure very small currents, the full length of wire $a\ b$, Fig. 16, carries the entire current that is to be measured. When used for larger currents, the wire $a\ b$ is tapped at one or more points by means of flexible silver strips, one of which is shown in Fig. 15 just below the scale, and the sections of the wire thus formed are connected in parallel in order to make the instrument of greater current-carrying capacity.

When still larger currents are to be measured, a shunt of special design is employed, which must be such that it gives a simple ratio of the current being measured to that in the meter itself. These devices are usually incorporated in the instrument, and when properly adjusted will require no further care. Consideration should always be made as to whether or not the meter is direct reading with or without the shunt. If the scale is arranged to give readings of current through the meter, these values should be multiplied by the multiplying power of the shunt. For instance, if the multiplying power of the shunt is ten, the meter reading should be multiplied by ten to obtain the actual current.

34. The expansion type of instrument is particularly useful in radio practice in measuring the very high-frequency currents which are commonly dealt with. This does not imply, however, that it is not suitable for the measurement of low-frequency, or direct currents. The types of ammeters commonly used in

the measurement of low-frequency currents are not applicable to the measurement of high-frequency currents, or at least would give erroneous values. The introduction of such an ammeter into a high-frequency circuit would seriously change its electrical properties on account of the undue opposition it would exert to the establishment of a high-frequency current. The expansion type of instrument having only a short, straight conductor is particularly free from this fault, and gives accurate readings at any frequency.

RESISTANCE

35. Ohm.—The **international ohm** *is the practical unit of electric resistance,* and is determined by the resistance of a column of mercury of specified dimensions or by a standard ohm coil. These standards are of interest only in making accurate scientific measurements; for general practical work, use is made of instruments that indicate either the resistance in ohms, or other measurements from which the resistance can be calculated. The resistance of conductors and insulators is usually expressed in ohms.

If a given conductor offers a resistance of 2 ohms to a current of 1 ampere, it offers the same resistance to a current of 10 amperes, provided that the temperature of the conductor is not changed. Hence, the resistance of a given conductor at a given temperature is always the same, irrespective of the strength of the current or the electromotive force of the current. The resistance of a conductor is a property of the conductor itself, depending on its dimensions, the material of which it is made, and its temperature; the resistance will remain the same, no matter what the current through the conductor, provided that the temperature is not allowed to change. In most cases, however, an increase of the current will cause an increase in the temperature of a conductor, because it is not usual to provide special precautions for keeping the temperature constant. Under such circumstances a change in current would be the indirect cause of a change in resistance.

If the length of a conductor be doubled, its resistance will be doubled; if its length be halved, its resistance will be halved; an increase in the length of a conductor or a decrease in its diameter will cause an increase in its resistance; a decrease in the length or increase in the diameter will cause a decrease in its resistance.

ELECTROMOTIVE FORCE

36. Volt.—The **volt** *is the practical unit of electromotive force*, and is the electromotive force that will cause electricity to flow at the rate of 1 ampere through a circuit with a resistance of 1 ohm. Because of the name of its unit, electromotive force is commonly called **voltage,** a name which has previously been mentioned and used, but not explained.

VOLTMETER

37. In practical work, voltage is measured by an instrument called a **voltmeter.** One common type is shown in Fig. 17. A voltmeter should be connected across a circuit, and will then indicate the electromotive force between the points on the line to which it is connected.

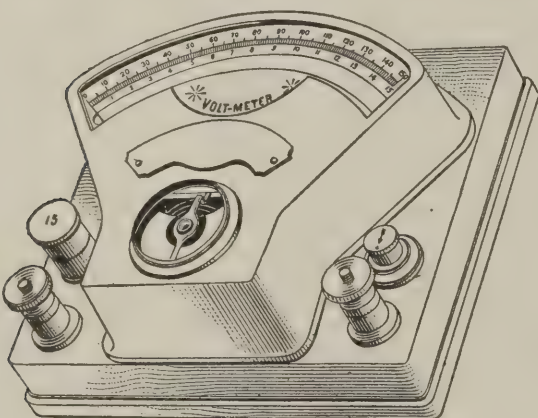


Fig. 17

In the electric system, the flow of electricity through the circuit is due to the electromotive force applied to the terminals of the circuit. This electrical pressure forces a current against the resistance offered by the wires and other devices connected in the circuit. The current through the voltmeter causes a deflection of its needle over a scale marked in volts. The electromotive force may be supplied by an electric battery or some other source of electric power.

If the resistance of a circuit remains the same and the electromotive force applied to its terminals is increased, the current will be increased. A decrease of the electromotive force will result in a decrease of current. If the electromotive force remains constant and the resistance of the circuit is increased, the current will be decreased; when the resistance is decreased, the current will be increased.

OHM'S LAW

38. The relation between the current, electromotive force, and the resistance is expressed by **Ohm's law.** The substance of the law has been given in the statement that flow of electricity increases with increased electromotive force, and decreases with increased resistance. In problems, current is commonly expressed in amperes, electromotive force in volts, and resistance in ohms. Ohm's law may be written in the following three forms:

Rule.—I. *Amperes equal volts divided by ohms.*

II. *Volts equal the product of amperes times ohms.*

III. *Ohms equal volts divided by amperes.*

EXAMPLE 1.—What current will result when an electromotive force of 6 volts is applied to a circuit having a resistance of 2 ohms?

SOLUTION.—Use of rule I gives current$=6\div2=3$ amperes. Ans.

EXAMPLE 2.—What electromotive force is required to establish a current of 5 amperes through a resistance of 4 ohms?

SOLUTION.—Use of rule II gives volts=amperes times ohms$=5\times4=20$ volts. Ans.

EXAMPLE 3.—What is the resistance of a conductor in which 6 volts will establish a current of 3 amperes?

SOLUTION.—Use of rule III gives resistance=volts÷amperes $=6\div3=2$ ohms. Ans.

ELECTRIC POWER

39. Watt.—The **watt** *is a unit of electric power* and represents a certain amount of work done in a unit of time. In any direct-current circuit, the power in watts equals the

product of the current in amperes and the electromotive force in volts, effective in that circuit.

The *kilowatt* (often written kw.) is also a unit of electric power in extensive use. One kilowatt equals 1,000 watts, the larger unit being an advantage in measuring large amounts of power.

ELECTRIC WORK

40. Watt-Hour.—The **watt-hour** *is a direct measure of electrical work* and equals 1 watt of power maintained for 1 hour. As this unit combines the elements of both rate and time, it is adapted to the measurement of the supply of electricity, that is, electrical work or energy.

Special electrical meters are made which measure the amount of electrical work or energy furnished by a circuit, and are commonly called **watt-hour meters.** As the name suggests, the reading may be in watt-hours, although the *kilowatt-hour* (1,000 watt-hours) is the unit generally employed for commercial purposes. The kilowatt-hour is often written kw.-hr.

WIRE GAUGES

41. Sizes of Wire.—Unfortunately, various standards of wire gauges have been adopted by different manufacturers, with the result that there is a lack of uniformity in this direction, which frequently causes confusion. The standards by which the various sizes of wire are designated are usually termed **wire gauges.** In each gauge, a particular number refers to a wire having a certain diameter. The size of wire generally decreases as the gauge number increases, but the law by which this decrease occurs is not the same in the different gauges. In the United States, copper wire is usually designated by the Brown and Sharpe, or American, wire gauge, which is generally termed B. & S. G.

42. Circular Measure.—A method that is extensively used for designating the size of a wire is to express its diameter in *mils* and the square of its diameter in *circular mils.* A

TABLE I

STANDARD ANNEALED COPPER WIRE

Size of Wire B. & S. Gauge	Diameter of Wire Mils	Circular Mils	Ohms per 1,000 Feet at 77° F.	Pounds per 1,000 Feet
0000	460	212,000	.0500	641
000	410	168,000	.0630	508
00	365	133,000	.0795	403
0	325	106,000	.100	319
1	289	83,700	.126	253
2	258	66,400	.159	201
3	229	52,600	.201	159
4	204	41,700	.253	126
5	182	33,100	.319	100
6	162	26,300	.403	79.5
7	144	20,800	.508	63.0
8	128	16,500	.641	50.0
9	114	13,100	.808	39.6
10	102	10,400	1.02	31.4
11	91	8,230	1.28	24.9
12	81	6,530	1.62	19.8
13	72	5,180	2.04	15.7
14	64	4,110	2.58	12.4
15	57	3,260	3.25	9.86
16	51	2,580	4.09	7.82
17	45	2,050	5.16	6.20
18	40	1,620	6.51	4.92
19	36	1,290	8.21	3.90
20	32	1,020	10.4	3.09
21	28.5	810	13.1	2.45
22	25.3	642	16.5	1.94
23	22.6	509	20.8	1.54
24	20.1	404	26.2	1.22
25	17.9	320	33.0	.970
26	15.9	254	41.6	.769
27	14.2	202	52.5	.610
28	12.6	160	66.2	.484
29	11.3	127	83.4	.384
30	10.0	101	105	.304
31	8.9	79.7	133	.241
32	8.0	63.2	167	.191

mil is a unit of length used in measuring the diameter of wires, and is equal to $\frac{1}{1000}$ inch; that is, 1 mil = .001 inch.

If the diameter of a wire is given in mils, the square of this number represents its circular mils. For instance, if a wire has a diameter of 80 mils, it will have $80 \times 80 = 6{,}400$ circular mils. It is quite common to state that the sectional area of a wire is a certain number of circular mils; this invariably means the square of the diameter expressed in circular mils.

The diameter multiplied by itself and by .7854 gives the area of a circular wire in square inches when its diameter is expressed in inches. Multiplying .7854 by the number of circular mils and dividing the result by 1,000,000 gives the sectional area in square inches, when the number of circular mils in a wire are known.

43. Wire Table.—The size, resistance, and weight of average commercial copper for the commonly used sizes of wire are given in Table I. The values are those given in a working table published by the United States Bureau of Standards, and have been commonly accepted in the United States. The values in this table are approximate, but are sufficiently accurate for practically all electrical calculations.

44. The ohms per 1,000 feet given in the table represent the resistance of 1,000 feet of wire of that particular size at the designated temperature (Fahrenheit). The resistance of 1 foot of conductor would be obtained by dividing the value as given by 1,000. Similarly, the weight of 1 foot of wire would be found by dividing the pounds per 1,000 feet by 1,000. The values of circular mils given in the third column should be the square of the diameter of the wire in mils as given in the second column. Any instances where the values in the third column are not the exact squares of those given in the second column are due to the fact that the values in the third column are calculated from more nearly accurate values than those given in the second column.

SKIN EFFECT

45. Skin effect is the name given to the cause of increased resistance of a conductor to alternating current above its resistance to direct current. The increase is due to the fact that alternating current seeks the outside of a conductor, thus reducing the effective cross-sectional area. The electric current is apparently evenly distributed in the conductor, when that current is direct. When, however, the current is alternating much of the current is near the surface of the conductor, and very little near the center. This distribution of the current is not manifest on low-frequency circuits, but becomes increasingly important as the frequency is raised. As, however, the frequency is fixed by the operating conditions, it is not practicable that it be decreased in order to reduce the skin, or surface, effect.

46. The skin effect may be so great that the resistance of a single solid conductor is only slightly less than that of a thin tube with the same outside dimensions. It is apparent then that there is considerable waste of material under these conditions, and in many cases tubes have actually been used. Another method of decreasing the amount of waste material and simultaneously increasing the surface of the conductor is by using many fine wires bunched together. Ordinary stranding of the uninsulated wires does not suffice, as those not on the outside are really not effective in reducing the skin effect. The usual practice is to braid the insulated wires together, such an assembly being known as **litzendraht,** or more often simply **litz wire.** In this construction the total area of all the conductors is effective in carrying a high-frequency current, and the resistance under such conditions is a minimum. An enamel covering on the wire or cotton insulation will act very well as insulating material to keep the conductors from touching one another. A woven tube construction, that is, with no wires in the center, gives very excellent results, but is not economical of space, and is rather expensive to manufacture.

MAGNETISM

MAGNETS AND MAGNETIC PROPERTIES

47. Kinds of Magnets.—A **natural magnet** is a piece of ore (a natural substance containing a mineral) that has the property of attracting pieces of iron, steel, and a few other metals. This ore was first discovered in the province of Magnesia, Asia Minor; the peculiar property was therefore called *magnetism,* and the name *magnet* was applied to a piece of ore possessing the property.

Later the discovery was made that if such magnets were suspended so that they could turn freely, all would come to rest in positions pointing north and south. Small bars of the ore were thus used to guide ships over the seas. They were therefore called *lodestones* (leading stone), a name that is also applied to the ore. These lodestones were thus the forerunners of the modern compass.

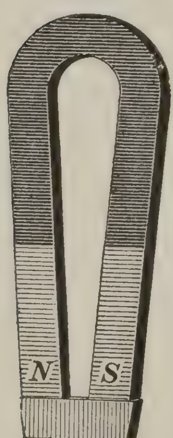


FIG. 18

48. A bar or a needle of hardened steel rubbed with a lodestone acquires properties similar to those possessed by the lodestone, and is called an **artificial magnet.** Artificial magnets that retain their magnetic characteristics for a considerable period of time, are called **permanent magnets.** Fig. 18 shows a common form of permanent magnet, consisting of a bar of steel bent into the shape of a horseshoe and then hardened and magnetized. A piece of soft iron called an *armature,* or *keeper,* placed across the two free ends, helps to retain the magnetism. Artificial magnets are also made in the form of a straight bar, as shown in some of the illustrations. Magnets of this type are sometimes used in small electrical machines and devices.

49. If a bar magnet is dipped into iron filings, the filings are attracted toward the two ends and adhere there in tufts, as in Fig. 19, while toward the center of the bar there is no attraction and the filings will not adhere there. If one end

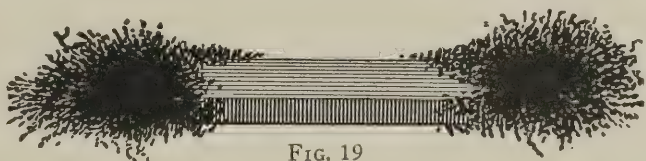


Fig. 19

of a magnetized bar of steel is brought near to a bit of soft iron, the iron will be attracted, and, if not too heavy, will be lifted by the bar and will adhere to it, as shown in Fig. 20. Exactly the same attraction will be exhibited by either end of the bar magnet toward such a piece of soft iron. The center portion of the bar magnet will, however, exhibit no such attraction. That part of the magnet *where* there is no apparent magnetic action is the

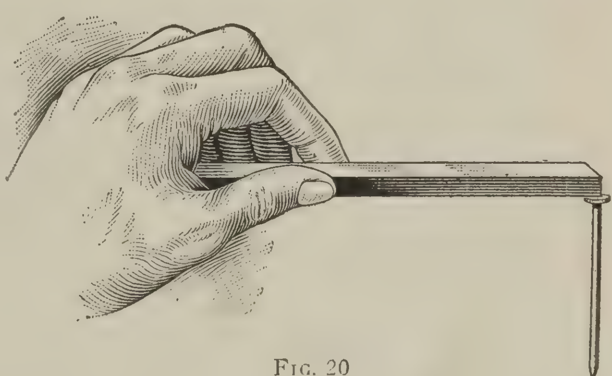


Fig. 20

neutral region, or *neutral zone,* and the parts around the ends which exhibit the power of attraction are called **poles.** An imaginary line drawn through the center of the magnet from end to end, connecting the two poles, is called the *axis of magnetism.*

Fig. 21

50. A **compass** consists of a magnetized steel needle, Fig. 21, resting on a fine point so as to turn freely in a horizontal plane. When not in the vicinity of iron, steel, or other magnets, the needle will come to rest with one end pointing toward the north and the other toward the south. The end pointing northwards is called the *north pole,* and the opposite end is called the *south pole,* meaning, respectively, *north seeking* and *south seeking.*

Every magnet has two equal poles, and the letters N and S appearing on illustrations of magnets are to indicate north and

Fig. 22

south polarity. If a long bar magnet is broken into any number of parts, as in Fig. 22, each part will still be a magnet and have two unlike poles.

51. Magnetic Attractions and Repulsions.—If one end of a bar magnet is brought near a compass needle, as in Fig. 23, the needle will be deflected from its north-and-south

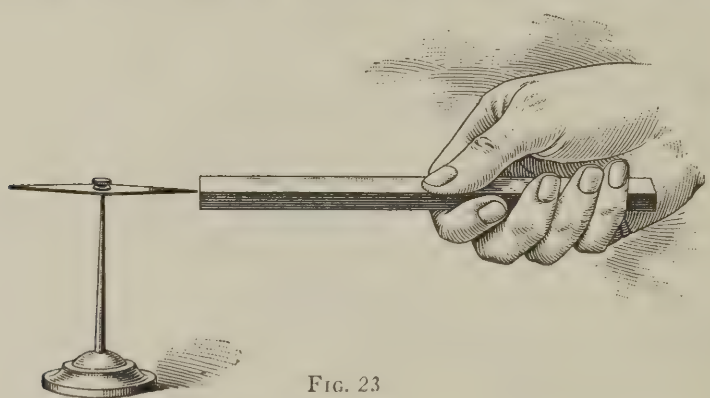


Fig. 23

position, one end being attracted by the permanent magnet and the other repelled. If the other end of the bar magnet is presented to the compass needle, the end of the needle which was formerly attracted will now be repelled. The two ends of the bar magnet, although acting alike in attracting iron filings and pieces of soft iron, must, therefore, be in some way different from each other, since one end will attract only the north pole of the compass needle, and the other end will attract only the south pole.

Fig. 24

This difference between the two ends of a permanent bar magnet will be further manifested if the bar is suspended at its center by a piece of fine thread,

as shown in Fig. 24. The bar will now be free to assume its own natural position and will finally come to rest with its longer axis pointing north and south exactly as in the case of the compass needle.

52. If the ends of the bar magnet are marked by the letters N and S to identify the north and south poles, and the magnet is again presented to the compass needle, it will be found that the north pole of the magnet attracts the south pole of the compass needle and repels the north pole, and that the south pole of the magnet attracts the north pole of the needle and repels the south pole. These experiments show the general law applying to all magnets, that *like magnetic poles repel each other while unlike poles attract each other.*

53. The reason why the compass needle or any freely suspended bar magnet takes a position with its north pole pointing north is that the earth itself is a great magnet, whose magnetic poles coincide nearly, but not quite, with the true geographical north and south poles. The laws of attraction and repulsion, just demonstrated by ordinary bar magnets, apply equally well to the attraction and repulsion between the earth's poles and the poles of the compass needle, or of any other magnet. There is one apparent inconsistency; like poles repel, yet the north pole of the compass needle is attracted by the north pole of the earth. As a matter of fact, the north pole of the compass needle is of opposite polarity to the north pole of the earth, otherwise these two poles would not attract each other. It would be more correct to call the north-seeking pole of the compass a south pole, or to call the earth's north magnetic pole a south pole, but the common custom is otherwise, and the confusion is one of names only.

54. Magnetic substances are those substances that are capable of being attracted by a magnet. Iron and its alloys are the principal ones, but nickel and cobalt possess mild magnetic properties. Nearly all other materials offer high opposi tion to the establishment of magnetism and are called *non-magnetic.*

55. Magnetic Field.—The space surrounding a magnet in which any magnetic substance will be attracted or repelled is its **magnetic field,** or simply its **field.** Magnetic attractions and repulsions are found to act in definite directions, and along imaginary lines, called *lines of magnetic force,* or also *lines of force.* A good idea of the field of force about a bar magnet may be shown by placing a sheet of cardboard over a magnet and sprinkling fine iron filings over the cardboard. If the cardboard is then gently tapped with a pencil or the finger, the filings will arrange themselves in accordance with the directions in which the magnetic forces act, that is, with the lines of magnetic force traversing the field. In the case of a

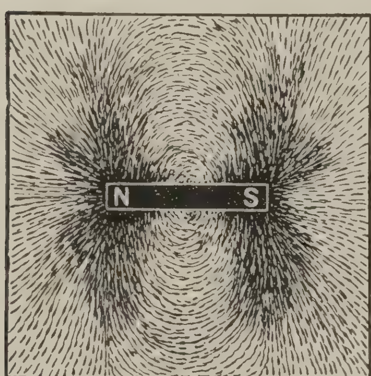


FIG. 25

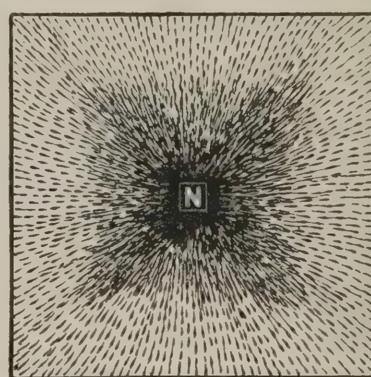


FIG. 26

bar magnet lying on its side, the filings will arrange themselves in curved lines, extending from the north to the south pole, as shown in Fig. 25. If the magnet is held perpendicular to the cardboard, the filings will arrange themselves in radial lines, as in Fig. 26. Lines of force must not be conceived as invisible threads, but merely as directions in which the forces act.

56. The direction of lines of force in a magnetic field can be tested by means of a small, freely suspended magnet, as the needle of a compass. The needle always turns until the direction of the lines of force within its body coincides with the direction of the lines of force in the field, as at *m,* Fig. 27. The north pole of the needle always points in the direction of the lines of force. Lines of force are usually represented by dotted lines and their direction by arrowheads on the dotted lines.

If a bar magnet is surrounded by air, the magnetic forces act in curved paths, connecting the poles, as indicated in Fig. 27, in which only a few lines of force are represented. The common assumption is that the forces act from a north pole and toward a south pole; that is, the lines of force pass out from the north pole, through the surrounding air, in at the south pole, and through the magnet to the north pole. This is called the *direction of the lines of force,* and the complete path is called the **magnetic circuit.** The total magnetism, or all the lines of force collectively, surrounding a magnet is called the flux of the magnet, or the **magnetic flux.**

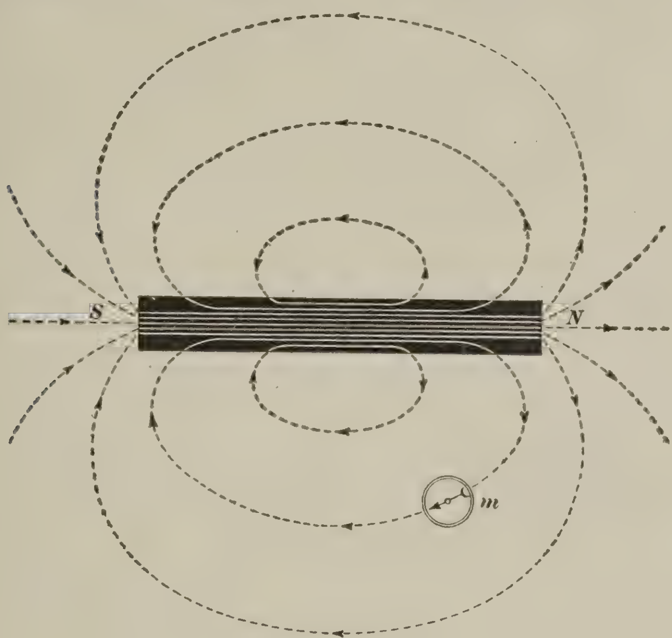


Fig. 27

57. Magnetic Induction. Magnetism may be **induced** in a magnetic substance, or produced by **magnetic induction,** by merely bringing the substance into a magnetic field. For example, if an unmagnetized bar of iron is laid on a cardboard, as in Fig. 28, iron filings sprinkled over it will

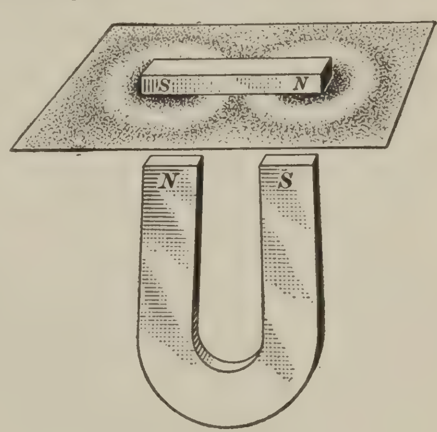


Fig. 28

show no tendency to cling to it, but if a horseshoe magnet is brought into the position indicated and the paper is gently tapped to jar the filings, they will cling to the ends of the bar as if it were a magnet. The lines of force crowd into the bar of iron and magnetize it in preference to going through the air, which is a non-magnetic material. The iron is a magnet as long as it is in the magnetic field. As is shown by Fig. 29, a chain of ordinary steel pens may be suspended from the pole of a permanent magnet, and each pen, being traversed by the lines of force emanating from the magnet, becomes a magnet to a sufficient extent to bear the weight of the pens below it. Each pen thus exhibits magnetic properties, its magnetism being induced.

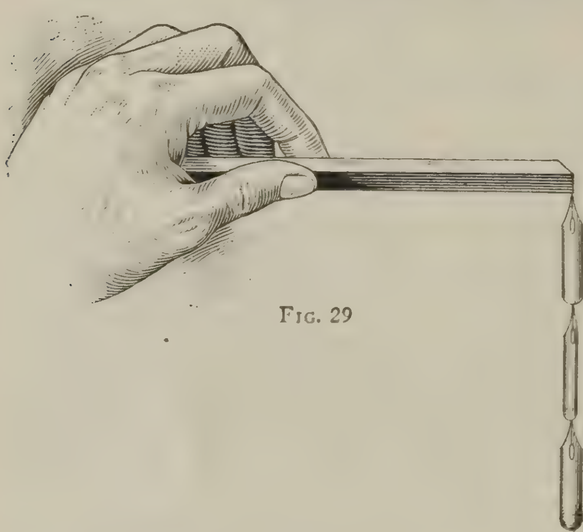


FIG. 29

58. Residual magnetism is the magnetism remaining in iron or steel after the magnetizing influence is no longer active. These two materials differ in their ability to retain magnetism, steel being much more retentive than iron, especially if the iron is of a soft grade. The pens of the experiment just described will probably show some power of attracting each other, even after the permanent magnet is removed. Very soft iron, on the other hand, although easily magnetized, will retain none of its magnetism after the magnet or other magnetizing source is removed. Poor grades of iron—that is, iron that is neither pure nor very soft—will retain some magnetism after the magnetizing source is removed, behaving in this respect somewhat like steel. Hard steel is difficult to magnetize to a high degree, but retains a large portion of its magnetism after the magnetizing force is removed.

ELECTROMAGNETISM

59. Magnetic Effect of Electric Current.—Every conductor carrying an electric current is surrounded by a magnetic field. This field has its maximum density in the space next to the body of a conductor, the density decreasing as the distance from the conductor increases. The magnetism thus established by electric current is called **electromagnetism.** It is no different from the magnetism of a permanent magnet, except in the method of establishing it.

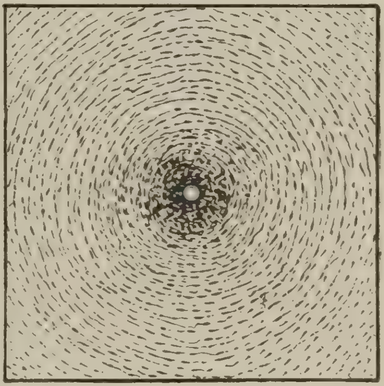


Fig. 30

If the conductor is threaded through a piece of cardboard and iron filings are sprinkled on the cardboard, they will arrange themselves in concentric circles around the conductor, as illustrated in Fig. 30. This effect will be observed through-

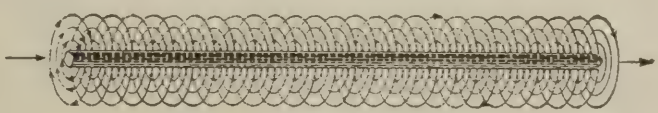


Fig. 31

out the entire length of the conductor; therefore, the field around any conductor carrying an electric current may be imagined as consisting of magnetic whirls, that entirely sur-

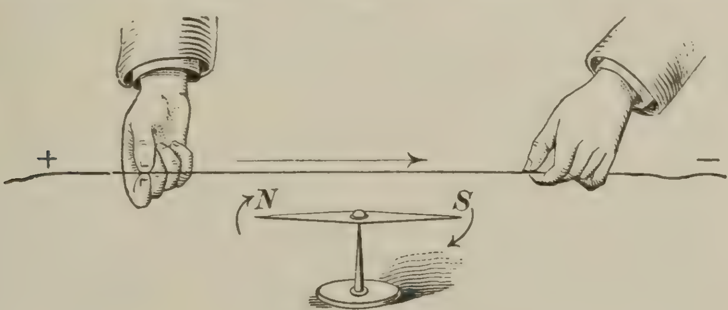


Fig. 32

round the conductor, as shown in Fig. 31. The condition shown in Fig. 30 can be shown by experiment, but that shown in Fig. 31 is inferred from the other.

60. Direction of Lines of Force Surrounding an Electric Current.—If a conductor carrying electricity in the direction indicated by the long arrow, Fig. 32, is held over a magnetic needle, the needle will deflect as indicated by the curved arrows toward a position at right angles to the direction of the conductor. If the conductor is then held under the needle, the needle will reverse its direction. Fig. 33 shows the indications of two compass needles, one above and one below a conductor carrying electricity, showing that the direction of the lines of force must be as indicated by the curved arrows. These experiments show that *lines of force encircle a current-carrying conductor clockwise when looking in the direction of the current.* The word *clockwise* means in the direction of movement of the hands of a clock or a watch and is made clear in Fig. 33.

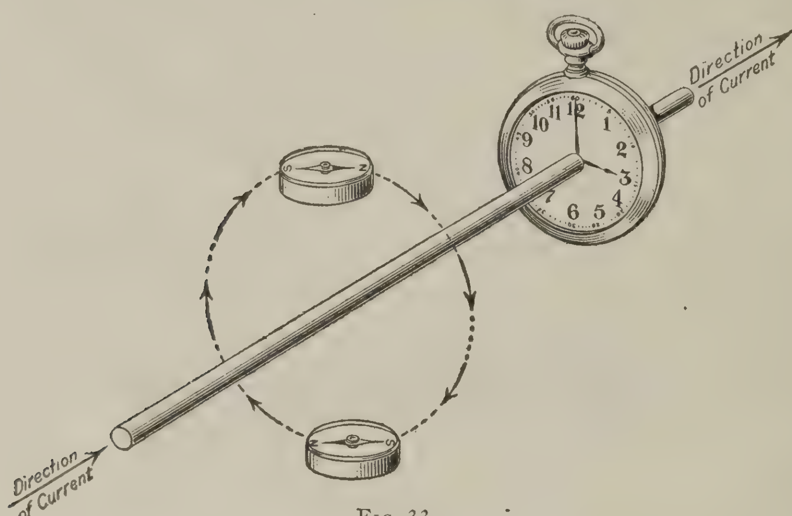


Fig. 33

61. In an actual experiment, the compass needles may not turn so nearly at right angles to the conductor as is indicated in Fig. 33, but they will approach the positions shown, their deflection depending on the strength of the current. Reversing the current will reverse the deflections of both needles, showing that the direction of the lines of force has reversed; but they still encircle the conductor clockwise to an observer facing the direction of the current.

62. Test for Direction of Current in a Conductor. The compass needle test can also be used to determine the direction of current in a conductor. If convenient, a portion of the conductor should be arranged in a north and south direction, parallel to the normal position of the needle. The compass should then be held near the conductor, and the needle will then indicate which way the magnetic flux encircles the conductor. If clockwise, looking along the conductor, the direction of current is from the observer; if counterclockwise, the direction of current is toward the observer. Fig. 34 (*a*) shows the compass under a current-carrying conductor and (*b*) shows the compass above the same conductor, the needles pointing in opposite directions; both positions indicate clockwise direction of flux looking north, showing that the direction of current must be north.

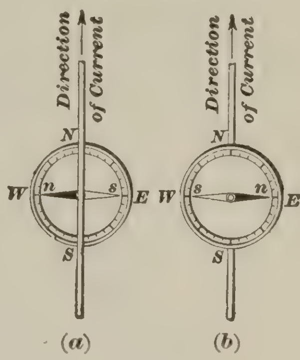


Fig. 34

63. A very simple way of remembering the relation between the direction of the current in a conductor and the direction of the lines of force surrounding it is to bear in mind the relation between the movement of a right-handed screw and the direction in which the screw must be turned in order to cause the movement. In Fig. 35 an ordinary screw is being driven into a board by means of a screwdriver. In order to make the screw move in the direction of the straight arrow, the screwdriver must be turned as shown by the curved arrow. If the movement of the screw into the board represents the direction of the current in a conductor, the rotary movement of the screwdriver represents the direction of the lines of force surrounding the conductor.

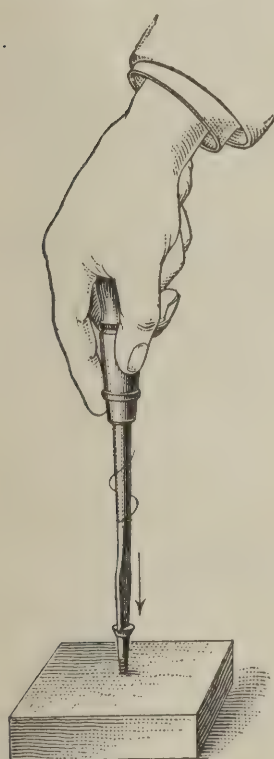
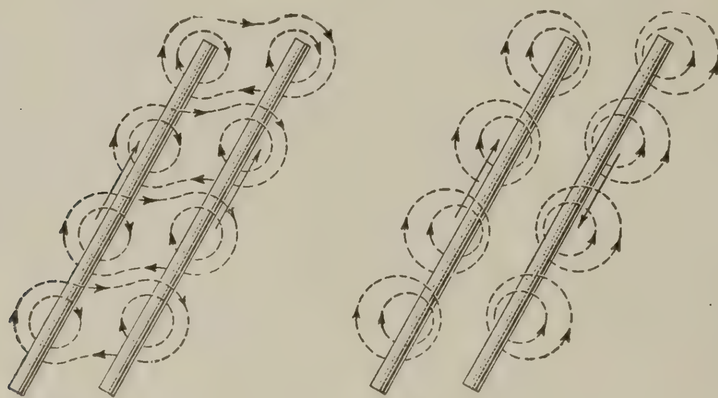


Fig. 35

64. Mutual Influence of Parallel Currents.—If two or more parallel conductors are carrying current in the same



(*a*) (*b*)

Fig. 36

direction, the magnetic flux surrounding them tends to draw them together. The lines of force around each conductor tend to unite with those of the other, forming a magnetic flux that encircles both the conductors, as in Fig. 36 (*a*), or all of them if there are several; the tendency of the lines of force to traverse the shortest possible path makes them act like elastic bands drawing the conductors together.

Two parallel conductors carrying current in opposite directions are acted on by a force tending to separate them. The lines of force, being opposite in direction, cannot unite around the conductors, but must all pass between them, as in Fig. 36 (*b*), thus tending to crowd them apart. In some electric

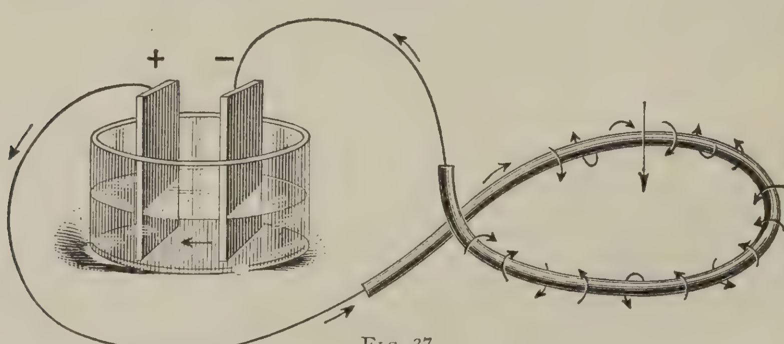


Fig. 37

apparatus, the stresses caused in this way sometimes become enormous when the currents are large. In such devices the

conductors must be fastened and braced very solidly to hold them securely in place.

65. Electromagnetic Solenoids.—An **electromagnetic solenoid** is a coiled conductor in which electricity is

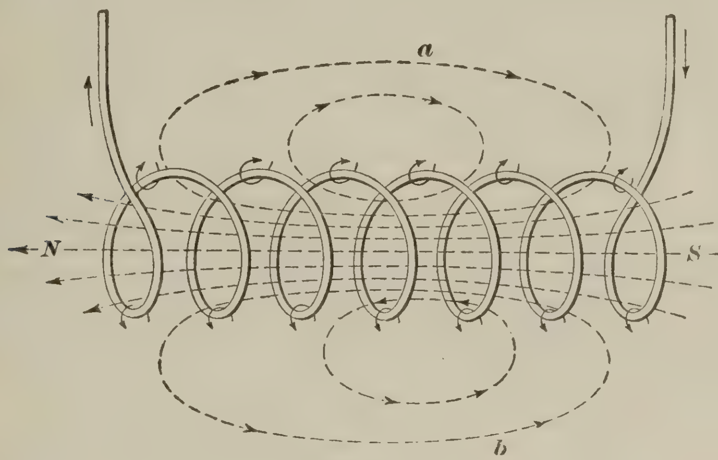


Fig. 38

flowing, the word *solenoid* alone being frequently used in referring to an electromagnetic solenoid. If a conductor is bent into a loop, as in Fig. 37, all the magnetic flux will pass through the loop in one direction as indicated by the long straight arrow. By bending the conductor into a long helix of several turns, as in Fig. 38, the effect is the same as piling a number of loops on each other, and some of the lines of force will thread through all of the turns in one direction. In this case the lines of force around each loop tend to combine with those around each adjacent loop, thus forming longer loops, each surrounding several adjacent turns of wire.

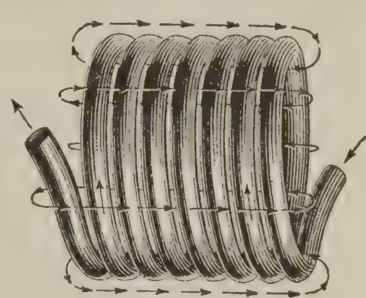


Fig. 39

Fig. 39 shows several turns of wire coiled into a helix with the coils close together. The lines of force, or magnetic whirls, about each individual turn have practically disappeared, being replaced by the longer lines of force threading through the entire helix and returning through the air, outside of the helix. In other words, the whirls surrounding each individual wire, as in Fig. 37, stretch so as to include all

of the wires in the helix, the result being a series of elongated whirls, or lines of force, all passing through the coil in one direction and back outside of the coil in the other direction.

66. The **polarity** of an electromagnetic solenoid can be determined without knowing the direction of current, by the method illustrated in Fig. 33. That method applied to Fig. 39 shows that the resulting magnetic field causes a north pole at the left end of the solenoid magnet and a south pole at the right end. The polarity can also be tested by holding a compass needle or a bar magnet near the end of the solenoid, remembering that unlike poles attract and like poles repel. Still another test is to suspend the solenoid so that it can swing freely to a north-and-south position. These experiments demonstrate the attractions and repulsions of solenoid magnets, which effects are similar to those of bar magnets.

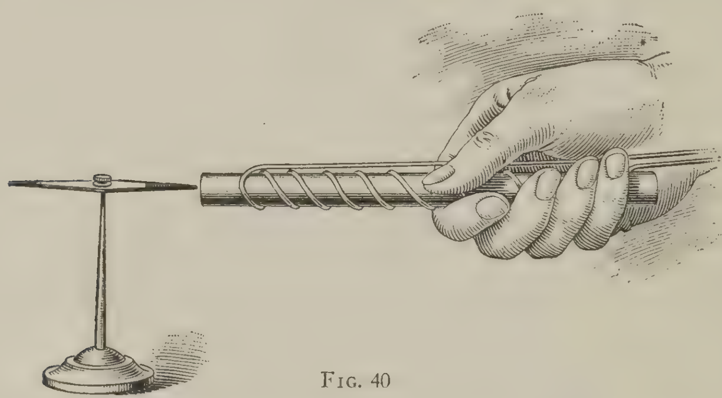


Fig. 40

67. Electromagnets.—An electromagnetic solenoid with a core of magnetic material is an **electromagnet,** and shows all the characteristics of a permanent magnet. The core is usually made of soft iron or steel, and exhibits magnetic properties when placed inside an electromagnetic solenoid. As magnetism is induced in the core, it will influence the poles of a compass needle, as shown in Fig. 40; one end of the electromagnet will attract the north pole of the magnet and repel the south pole, while the reverse is true of the other end of the electromagnet. The solenoid, or winding, is commonly called the *magnetizing coil.*

68. The polarity of an electromagnet and the direction of current in its exciting coil can be determined by the methods previously described. For example, if the bar-type electromagnet, Fig. 41, is held so that the current encircles it clockwise, the end toward the observer is the south pole; or if the polarity is first determined by some other test, as with a compass, and the observer faces the south pole, the direction of the current is clockwise.

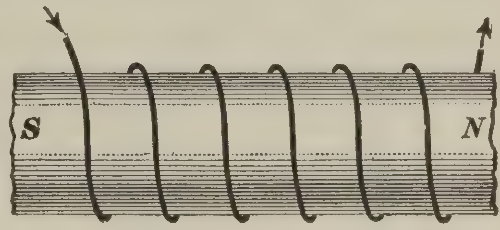


Fig. 41

If the current ceases in an electromagnet the core loses nearly all of its magnetism; and a reversal of current in the coil causes a change in the direction of the magnetism through the magnetic circuit. If an electromagnet were suspended by its center so that it could turn freely, it would come to rest in a north-and-south position, similar to a permanent magnet. If the direction of the current in the coil is reversed, the polarity of the electromagnet will be reversed, the north pole now becoming the south pole and vice versa.

An iron core greatly increases the effect of the current in a solenoid in establishing a magnetic flux because iron affords a very much better path for the lines of force than non-magnetic substances as air, wood, brass, copper, or hard rubber. The result is, therefore, that when an iron core is placed within an electromagnetic solenoid, the number of lines of force will be greatly increased, and the magnetic pull of the solenoid will be much stronger than it would be without the iron core.

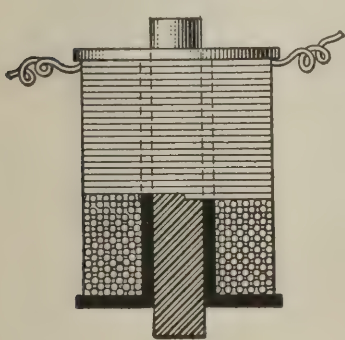


Fig. 42

69. The forms of electromagnets are many and varied. The simplest form is the straight-bar magnet, or single-coil magnet, as shown in Fig. 42, in which the lower part of the electromagnet is represented in section. The most convenient form for a great variety of

uses is the horseshoe, or **U**-shaped, magnet, illustrated in principle in Fig. 43. This sometimes consists of a bent bar of soft iron and two magnetizing coils, one on each end, or leg, of the magnet. The current in the windings on a horseshoe magnet is in opposite directions around the two legs, that is, clockwise around one leg and counterclockwise around the other, as is indicated in the sectional view. In this way a north pole is produced at one end of the core and a south pole at the other end.

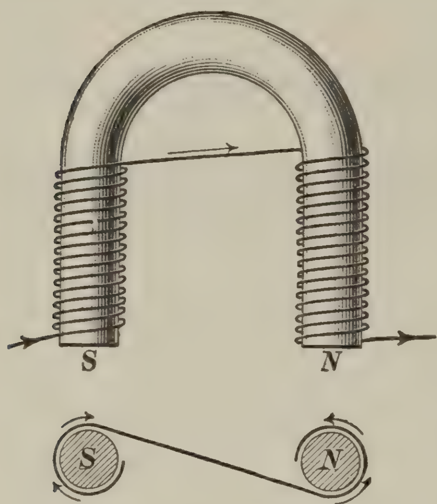


Fig. 43

For convenience in manufacture, the **U**-shaped electromagnet, or two-coil magnet, is usually made in parts, as shown in Fig. 44; namely, two straight round-iron cores, two magnetizing coils, and a straight iron bar, or yoke *b*, joining the two cores together. The right-hand core *M* and its coil *c* are shown in section, that is, as they would appear if cut on a plane passing through the axis of the core. The heavy black lines represent the insulating spool on which the wire is wound. At the left is shown the exterior of the other coil and the position of its core is indicated by the dotted vertical lines.

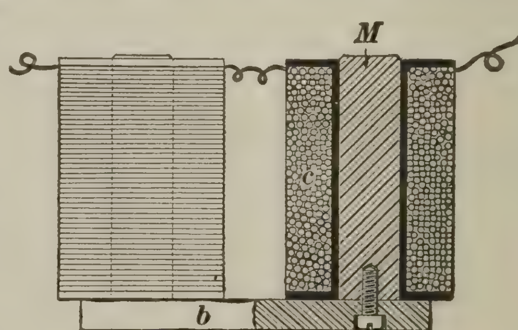


Fig. 44

70. The **magnetizing coil** of an electromagnet usually consists of a large number of turns of insulated wire, that is, wire covered with insulating material, such as silk, cotton, or enamel. If the wire and core were bare, the current would take a shorter and easier path from the wire to the core, or from one turn of wire to adjacent turns. This would defeat the purpose of the structure, for in

order to produce an electromagnet it is necessary that the electricity be made to travel around and around the core, through all of the convolutions of the wire. The common practice is to insulate the core itself with a layer of paper or cloth, and to make the heads of the spool either of insulating material, or, if of metal, to provide them with a layer of insulating material on their inner faces.

GENERATION OF ELECTROMOTIVE FORCE
(PART 1)

ELECTRIC CELLS

INTRODUCTION

1. Methods of Generating Electromotive Force. The methods most commonly used to establish an electromotive force are: (1) by chemical action in *primary cells;* (2) by heat action in *thermoelectric couples;* and (3) by electromagnetic induction in *electric generators.* These methods of establishing an electromotive force will be considered in this Section. Other devices such as *storage batteries* and *transformers* will be explained, although they are not generators of electricity in the strict meaning of the word. In the storage battery, electrical energy is stored up by chemical action, and in a transformer the energy is transferred into more suitable electrical values, hence these devices are really accessories employed in the utilization of electrical energy.

PRIMARY CELLS

GENERAL THEORY

2. A **primary, voltaic,** or **galvanic, cell,** as it is variously called, is an apparatus for converting chemical energy directly into electrical energy. The cell consists of two conducting elements immersed in a solution that acts chemically on one element only or on one more than on the other. If the

two elements or poles of the cell are joined by a continuous metallic wire or circuit, electricity will flow in one direction through the metallic circuit as long as the circuit remains complete, or closed, provided the chemical action is sufficient to maintain the electromotive force.

3. While a knowledge of the chemical actions that occur in cells is interesting and necessary for a thorough understanding of the theory of cells, it involves a knowledge of chemistry that is not really necessary for those having only to consider the proper application of the various kinds of cells and their care.

In general, it may be considered that the electrolyte is divided into very small electric charges, which combine to produce the electric current observed in the circuit connecting the poles. The cell is said to be *charged* when it is in condition to deliver its full rated amount of electrical energy. Primary cells are fully charged just as manufactured. The electrolyte deteriorates, or loses its strength, as energy is given up, and is said to be *discharged* when it can furnish no more electrical energy.

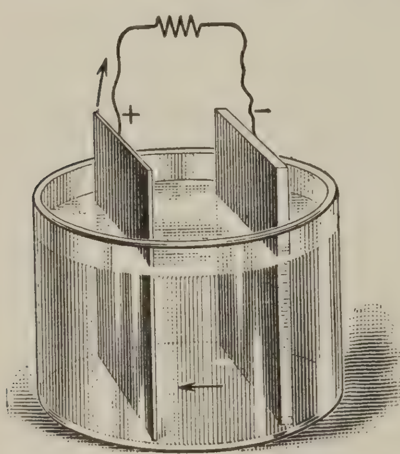


Fig. 1

Some forms of primary cells may, when exhausted, be more or less *recharged* by passing through them, in the direction opposite to the current they produce, a current from some external source. As the amount of energy which the primary cell will give up after recharge is very small compared with the amount required to recharge the cell, this is not considered good practice.

4. A simple primary cell is shown in Fig. 1, with the two plates or elements partly immersed in the electrolyte. Zinc is the metal most commonly used for the element of the primary cell to be consumed, and either copper or carbon for the element that is not attacked. The electrode from which electricity enters the electrolyte is the **anode,** and the electrode

toward which electricity flows in the electrolyte is the **cathode;** thus, the electrode with the negative terminal is the anode, and the electrode with the positive terminal, the cathode. The current passes into the cell through the anode and passes out to the external circuit through the cathode.

5. Many different electrolytes are used in primary cells, the materials used depending largely upon the service for which the cell is intended. The simplest electrolyte is salt water, or water with a little acid added. The zinc electrode is attacked by the electrolyte, which gradually eats the zinc away, and simultaneously changes the nature of the electrolyte by decomposition.

6. Polarization and Depolarization.—During decomposition of the electrolyte, free hydrogen is liberated near the cathode, and, if not removed, collects on the cathode in bubbles of gas. The formation of hydrogen is disadvantageous, as it forms in a layer on the surface of the cathode, enormously increasing the internal resistance of the cell, and diminishing the current that the electromotive force of the cell can send through any given external resistance. The formation of hydrogen on the surface of the cathode is known as **polarization,** and its removal, by any means, mechanical or chemical, is called **depolarization;** the agent used is called the *depolarizer.*

7. Depolarizing Agents.—Various mechanical and physical devices for depolarizing cells have been used. The cathode has been arranged to be agitated in the liquid, or to be entirely removed from the liquid at intervals. The cathodes, and, in some instances, both electrodes have been made in the form of disks, dipped to about half their diameter into the electrolyte; on rotating the disks, the hydrogen is prevented from remaining on the cathode by its motion. Such devices are commercially of little value, especially as chemical depolarizers may be more easily used.

The depolarization by chemical means may be accomplished by surrounding the cathode with a solid or liquid substance, with which free hydrogen may combine. This combination

usually merely disposes of the hydrogen and prevents the bad effects of a deposit on the cathode. Under these circumstances the compound formed at the cathode is usually water, the depolarizer being a substance rich in oxygen, with which the hydrogen combines. Various means are employed to keep the depolarizing agent near the cathode. A typical chemical depolarizer will be discussed in the explanation of the *gravity cell* which will follow.

DANIELL CELL

8. The **Daniell cell,** uses for the anode, zinc; for the electrolyte, a solution of zinc sulphate; for the cathode, copper; and for the depolarizer, a solution of copper sulphate. As the electrolyte and depolarizer are in some types kept separate by gravity, due to the greater weight of one of the liquids, such cells are often placed under the general heading of *gravity cells.*

Fig. 2

A form of gravity Daniell cell extensively used in the United States is the *crowfoot cell,* shown in Fig. 2, where *Z* is the zinc, from the shape of which the cell gets its name; *C* is the copper, which is connected to the external circuit by the wire *W,* which is insulated where it passes through the liquid. When the cell is set up the copper cathode is surrounded with copper-sulphate crystals. The cell as usually constructed furnishes a working electromotive force of 1 volt. For continuous working, the most economical current output is about $\frac{1}{4}$ ampere. Its internal resistance depends on the condition of the cell; 3 ohms is an average value.

DRY CELLS

9. The name *dry cells* is applied to cells in which the electrolyte is carried in the pores of some absorbent material, or combined with some gelatinous substance, so that the cell may be placed in any position without spilling of liquid. These cells are usually made with zinc and carbon elements. The zinc usually forms the outside of the cell, being made into a cylindrical can; in the center of this is the carbon, surrounded by its depolarizing compound. The space between the elements is filled with some absorbent material, such as mineral wool, asbestos, sawdust, blotting paper, etc., and the whole, including the depolarizer, is then soaked in the electrolyte; or, the electrolyte is mixed with a hot solution of some gelatinous body, such as Irish moss, which mixture is poured into the cell; on cooling, it forms a soft jelly. The first method of preparation is most used. It is quite necessary for dry cells to have a depolarizer, as otherwise they would have to be made open to allow the hydrogen gas to pass off. This would also allow the small content of water to evaporate. To prevent this latter action, these cells are sealed with a resinous compound. To insulate the cell, the zinc is covered with pasteboard.

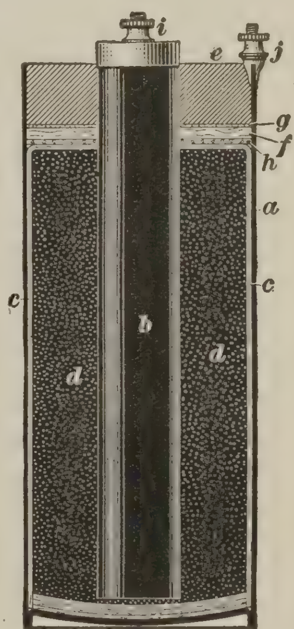


FIG. 3

10. Fig. 3 shows the cross-section of a dry cell such as has just been described. The zinc container *a* forms the anode, or negative terminal, of the cell, with a connector at *j*. The cathode, or positive terminal, is a carbon rod *b*, placed in the center of the can with a connector at *i*. The electrolyte in this case is a solution of sal ammoniac that is absorbed by a pulpboard lining *c*, and the mixture *d* is of powdered carbon and manganese dioxide. The latter is the depolarizing agent. The cell is closed by a water-tight seal *e* that is separated from the

lining *c* by a layer of corrugated paper *f*, which is prevented from adhering to the seal by a layer of fine sand *g*. A layer of sawdust *h* separates the corrugated paper from the lining *c*. The purpose of the corrugated paper is to serve as a cushion between the seal and the mixture, thus allowing for any expansion or contraction in the cell.

There are many modifications in the general arrangement and kinds of materials which are used, but the fundamental principles remain the same. Dry cells are manufactured in very compact units for pocket flashlights and for certain wireless applications where a relatively high voltage is required with only a very small current output.

GENERAL USES

11. Some types of wet cells are more economical than dry cells, and provide a limited amount of electrical energy at a very reasonable cost. Dry cells are very convenient, readily portable, of small bulk, and relatively cheap as compared with wet cells. The advantages mentioned have offset the disadvantage that this type of cell cannot be economically refilled or recharged. The result is that they have largely replaced wet cells in many lines of work. Even the best dry cells will not usually remain in good condition longer than three years, while the poorer ones depreciate in much less time. Dry cells should be kept in a cool dry place whenever possible. The internal resistance of fresh dry cells varies from .1 to .7 ohm and the electromotive force from 1.3 to 1.6 volts. Dry cells of ordinary size should not be used where a current exceeding about .2 ampere is required. Dry cells find their greatest usefulness in intermittent service and in furnishing a fairly high voltage with small current consumption.

STORAGE CELLS

GENERAL CLASSES

12. The *storage cell, secondary cell,* or *accumulator,* as it is variously called, is fundamentally the same as a primary cell, but differs in this respect, that when discharged, either wholly or partly, the storage cell can be restored or recharged, by passing current through it in the reverse direction for a sufficient length of time. The material of the electrodes that undergoes chemical changes during charge and discharge, called the *active material,* is generally supported on the surface or in the openings, or pockets, of a conducting framework, called a *grid.* The grid with its active material is called a *plate.* Each electrode in a storage cell consists of a plate or of a group of plates connected in parallel. The plates of the positive electrode alternate with those of the negative, in order to provide the shortest path for the current through the electrolyte. The two outside plates are negative since there is one more negative plate than positive plate. Two types of commercial storage cells are in use: the *lead-sulphuric-acid cell,* sometimes called simply the *lead cell,* and the *nickel-iron-alkaline cell,* known also as the *nickel-iron,* or *Edison, cell.* The names are derived from the chemical natures of the electrodes and electrolytes.

THE LEAD-SULPHURIC-ACID CELL

13. Construction.—In the lead-sulphuric-acid cell the grids, both positive and negative, are of lead or of lead-antimony alloy. The electrolyte is a solution of sulphuric acid, formed by mixing 1 part of pure concentrated acid with 2.5 parts, by weight (4.5 parts by volume), of distilled water. The specific gravity of the electrolyte—that is, the ratio of the weight of a given volume of electrolyte to that of an equal volume of water—is about 1.2. Two fundamental, or general, types of plates have been developed for use in the lead cell: the *Planté,* or formed, plate, and the *Faure,* or pasted, plate.

14. The Planté plate, so called after its inventor, Gaston Planté, consists of a sheet or a grid of pure lead, usually ribbed or corrugated, in order to increase the superficial area. By an electrolytic process the active material is formed on the surface of the plate from the metal composing the plate. This type of plate is rather heavy and costly, but is very durable. The formed plate cell is commonly used in stationary batteries requiring a comparatively large amount of work per year, making durability of primary importance.

15. The Faure plate, invented at practically the same time by Faure in France and by Brush in the United States, consists of a grid provided with ribs, openings, or pockets, to which is applied the active material in the form of a paste consisting of red lead for the positive plate and of litharge for the negative. After the paste has set, the red lead of the positives is changed to lead peroxide and the litharge of the negatives to pure sponge lead by passing current through them in the proper direction in the forming bath of dilute sulphuric acid. The pasted type of plate is almost exclusively used in portable cells, where weight and space are of more importance than durability.

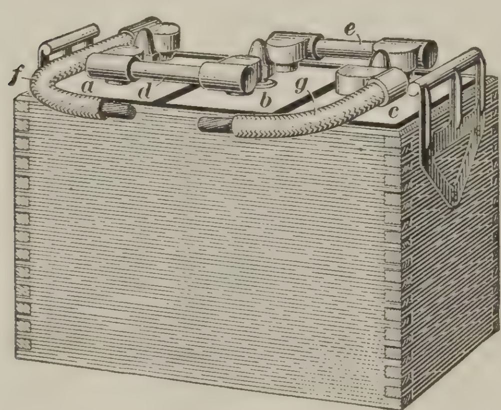


FIG. 4

16. An external view of a portable storage battery, which is also a good example of the lead-sulphuric-acid cell, is shown in Fig. 4. The battery consists of three cells *a*, *b*, and *c* that are contained in a wooden box. The cells are electrically connected by two conductors *d* and *e* that connect the positive terminal of each cell with the negative terminal of the next. The terminals of the battery are shown at *f* and *g*.

17. The construction of the ordinary type of storage battery is shown in Fig. 5, which shows one cell of the battery

cut in two crosswise, exposing to view the various parts. The elements of each cell are contained in a semiflexible rubber jar *a* that carries the plates *b* and *c* on supports *d* and thus provides a space in the bottom of the jar for any sediment from the plates. Like plates, that is, either the positive or the negative plates of a cell, are connected at each end, as shown at *e* and *f*, and a terminal from each set of plates is brought up through the top of the battery. In the cell shown, one terminal *g* is a battery terminal while the other terminal *h* is connected to the adjoining cell. When the cell is in working condition, the electrolyte, which consists of sulphuric acid and water, should fill the jar high enough to cover the plates, or, when the cell is freshly filled, up to the first cover *i*. Provision is made by means of a removable plug *j* for the addition of water at regular intervals as the water in the electrolyte evaporates. The plug contains a small hole that serves as a vent, through which liberated gases may escape. An expansion chamber *k* is provided in the upper part of the cell for changes in the volume of the electrolyte during charging or discharging. A top cover *l* of polished hard rubber is placed over the expansion chamber and sealed acid-tight. The outer wooden box *m* is provided with an expansion joint *n* to allow for any changes in its volume. A plastic sealing compound *o* surrounds the rubber containing jar between it and the box, and acts as a cushion. The wood separators, which are placed between the adjacent plates, are hidden from view by the plates. These prevent the positive and negative plates from touching each other and thus short-circuiting the cell and rendering it inoperative.

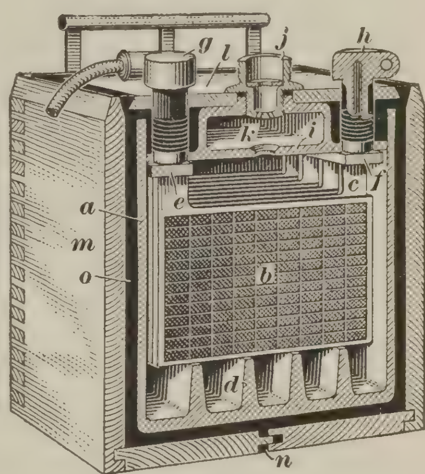


Fig. 5

18. A part sectional view of the rubber containing jar used in the battery is shown in Fig. 6 (*a*). One side of the

jar is shown partly removed in order to expose to view the supports on which the elements rest. A detailed view of the plates, arranged as they are in the cell, is shown in Fig. 6 (*b*). The like plates of each cell are connected by means of connecting straps *a* and *b*, to which the terminal posts are attached. The outline of the framework of the plates in which the lead is pressed can be seen. One of the separators, which for this

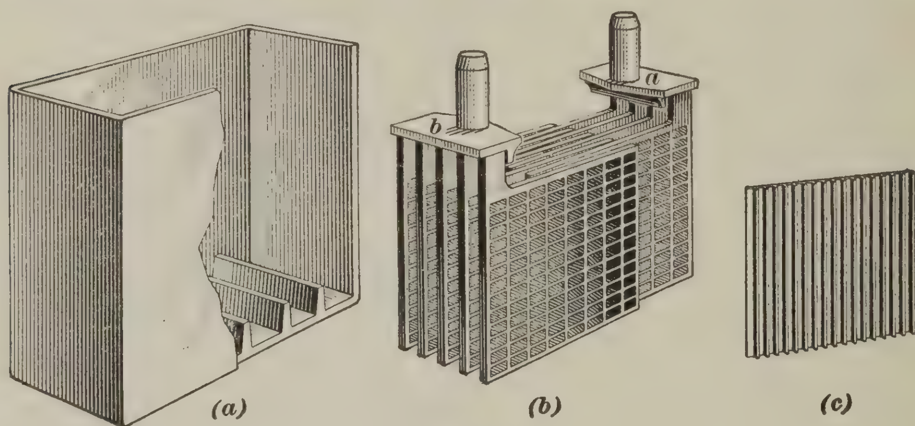


FIG. 6

particular battery are made of wood, is shown in view (*c*). In some makes of batteries porous rubber separators, or both wooden and rubber separators, are used. The rubber separators would, in the latter case, be placed between the wooden separators and the positive plates as the rubber separators might embed themselves into the soft sponge lead if placed adjacent to the negative plates.

19. Normal Voltage.—The normal discharge voltage of a storage battery is usually taken as 2 volts per cell, this being about the average voltage delivered during the normal discharge of a cell, as shown by Fig. 7, which represents typical charge and discharge curves for a lead-plate cell. For instance, the normal discharge voltage of a three-cell storage battery is 6 volts, although the actual value of the voltage of the battery, when fully charged, is approximately 1 volt higher. Storage batteries are generally designated by their normal voltages, as, for instance, a 6-volt battery, a 12-volt battery, a 16-volt battery, and so on. When the voltage has dropped to about 1.7 per cell, the battery should be recharged, because it retains

only a comparatively small amount of electrical energy at this pressure and the voltage drops rapidly during discharge after getting below 1.7. The life of the battery is shortened by discharging below 1.7 volts per cell. The voltage usually remains fairly constant for a discharge at normal rate, but drops off rapidly if the battery is discharged at a more rapid rate.

The value of the time or voltage may be easily obtained from Fig. 7, when the value of one of these factors is known.

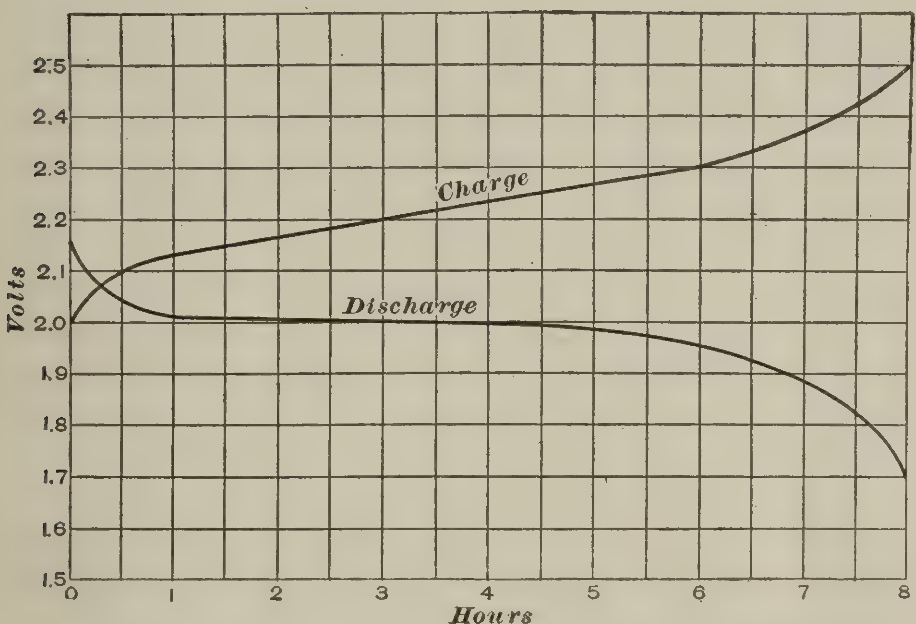


Fig. 7

For instance, if the voltage at any particular time is desired, the proper value in hours is obtained on the lower horizontal scale. Then follow the vertical line above that point until it cuts the proper curve. Then trace horizontally to the left until the vertical scale is reached and the voltage value is then read. Suppose the voltage is desired after the cell has discharged for three hours. Follow the vertical line above *3* until it cuts the discharge curve. Then, follow the horizontal line to the left and it will show that this line cuts the vertical scale at *2.0* and the voltage is therefore 2.

If the voltage impressed on the cell after the cell has been charged for 3 hours is desired, it is necessary to follow the

vertical line above *3* until it cuts the charge curve. Following the horizontal line to the left scale shows that the corresponding charging voltage is 2.2.

20. Specific Gravity.—The **specific gravity** of a substance is the quotient obtained by dividing the weight of a given volume of the substance by the weight of the same volume of some other substance used as a standard. Pure water is usually taken as the standard for solids and liquids. It will be noted that the strength, or specific gravity, of the electrolyte decreases during discharge and increases during charge, and furnishes an indication of the state of discharge of the cell. A fully-charged cell should show a specific gravity of the electrolyte of from 1.275 to 1.300. The cell is practically discharged when the specific gravity is as low as 1.150, and recharge should be started as soon as possible. In practice the specific gravity is often used as a whole number. For example, a specific gravity of 1.275 is often called simply twelve seventy-five.

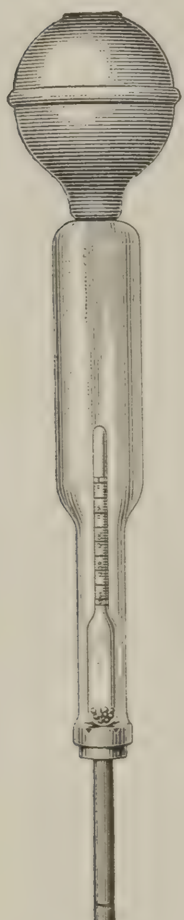


FIG. 8

21. The *hydrometer* is used for measuring specific gravities of electrolytes, and may be obtained with numbered scales ranging between 1.100 and 1.300. The hydrometer sinks into the liquid, and the reading is taken on the scale at the level of the top of the electrolyte. A convenient device is the *hydrometer syringe*, Fig. 8, which consists of a rubber bulb provided with a glass barrel containing the hydrometer. The electrolyte is drawn up into the barrel until the hydrometer floats, when the reading may be taken, and the electrolyte then returned to the cell. The hydrometer test represents one of the most accurate methods of determining the condition of a cell, and is perhaps the one used most.

It is not good practice to test the condition of a battery by temporarily connecting the terminals by a short wire and

noting the spark produced when the connection is broken. The wire short-circuits the battery and the short circuit will probably injure the plates. The practice is to be strongly condemned.

22. Assembling.—Special instructions are furnished by the manufacturers for assembling and connecting up the cells of a battery. The following are the more important precautions to be observed:

The positive and negative groups should first be assembled in the containers and connected up before the electrolyte is put in, the positive terminal of each cell being connected to the negative terminal of the adjacent cell. The wooden separators should be kept wet until they are placed in position in the cells, and the electrolyte should then be added before the separators are allowed to dry.

Electrolyte of the proper density for immediate use is usually furnished. If strong acid (oil of vitriol, or 1.800 specific-gravity sulphuric acid) is obtained, it must be diluted with pure water before being poured into the cells. This diluting, or breaking down, of strong acid must be done with great care, as a large amount of heat is developed during the operation. *Never add the water to the acid,* as this will produce dangerous sputtering. Add the acid to the water very slowly, especially when a glass vessel is used, in order to avoid cracking the glass with excessive heat, and stir constantly during the process. Allow the mixture to cool before putting it into the cells.

23. Polarity.—Before connecting a battery to the charging circuit, the polarity (positive or negative) of each of the two conductors of the charging circuit must be determined. If there is any doubt as to this, a simple test may be made by connecting two wires, one to each conductor of the supply circuit, with enough resistance in series to limit the current to about 1 ampere or less, and then dipping the two wires in a vessel of acidulated water or in water in which a small amount of common salt has been dissolved, keeping the ends of the wires about an inch apart. The wire from which bubbles

of gas are given off more freely is connected to the negative side of the circuit. The positive terminal of the battery must then be connected to the positive conductor of the circuit, and the negative terminal to the negative conductor. The positive terminal of a stationary battery may be distinguished by the dark-brown color of the plates to which it is connected, the negative terminal being connected to the slate-gray plates. The terminals of portable batteries, in which the cells are sealed, preventing inspection of the plates, are usually marked for polarity. If they are not marked, a voltmeter may be used or the test just described may be employed.

24. Initial Charge.—Immediately after assembling and as soon as possible after the electrolyte has been put into the cells, charging should be started and continued at the 8-hour rate, with as little interruption as possible, for a period of from 35 to 60 hours, depending on the type of plate. Special instructions are furnished by the manufacturers.

25. Regular Charge.—A regular charge is given to the battery as frequently as may be necessary to restore the energy taken out on discharge. This regular charge can be given at the normal rate throughout; but if it is necessary to hasten the charge, a much higher rate can be used at the beginning, provided the rate is reduced from time to time to prevent violent gassing and to keep the temperature of the cells below 110° F. The regular charge should be continued until the specific gravity of the pilot cell is from 3 to 5 points below the maximum reached on the preceding overcharge. All the cells should then be gassing moderately, but not so freely as at the end of overcharge.

When a battery has been completely discharged, the charge should be started as promptly as possible. Long standing in a discharged condition tends to produce in the plates a hard and crystalline form of lead sulphate that will reduce their capacity temporarily. This sulphate may not cause permanent injury, because it can be decomposed by a long overcharge at low rate.

26. The most reliable indication of a complete charge in a lead cell is the fact that the voltage and specific gravity have reached a maximum and become stationary for 15 minutes to ½ hour, the charging current being kept constant. These final values of voltage and specific gravity are not always the same, the former varying with the temperature, the rate of charge, the type of plates, and the age of the battery; and the latter with the temperature, the height of the electrolyte, and the amount of acid lost by spilling, gassing, or combining with sediment in the bottom of the cell.

27. Toward the end of the charge the cells will gas very freely, an indication in a healthy cell that the charge is nearing completion. While charging portable cells in sealed rubber jars, the soft-rubber stoppers in the covers should be removed and the cover of the battery box or compartment should be left open.

It should always be borne in mind that the gases, oxygen and hydrogen, given off by a battery toward the end of charge form an explosive mixture. The battery room or compartment should therefore be freely ventilated at such times, and the proximity of an exposed flame should be absolutely prevented.

28. The electrolyte should be kept above the tops of the plates by filling the cells with chemically pure water from time to time. The local supply of water may be sufficiently pure, but the use of distilled water is strongly recommended in all cases. Water for filling cells should be stored and handled in wooden, earthenware, or glass vessels; the use of vessels made of iron or other metals should be avoided. Under normal conditions of temperature and ventilation, filling and inspection once a week is sufficient. The acid in the electrolyte does not evaporate, and during normal operation should never be added to the cells except by special instructions from the manufacturer.

29. Putting Battery Out of Commission.—If the use of the battery is to be discontinued entirely for a period

not longer than 9 months and it is not practical to charge at least once a month, care should be taken that an overcharge is given just before the idle period. Water should be added to the cells during the overcharge so that the gassing will insure thorough mixing. The level of the electrolyte should be about $\frac{1}{4}$ inch from the top of the jars. After the overcharge is completed, the operator should be sure that all the cell covers are in place and the battery fuses removed. Though not likely, the level of the electrolyte may, owing to excessive evaporation during the idle period, fall below the top of the plates; if this should occur, water must be added to keep them covered; if in a place where freezing is apt to occur, the electrolyte should be stirred after adding the water to insure thorough mixing.

When a battery is stored it should be put in a cool place but not allowed to freeze. A battery that is completely discharged will freeze at about 20° above zero, Fahrenheit, while one having a specific gravity of 1.210 will freeze at 20° below zero, Fahrenheit.

30. Returning Battery to Commission.—If, in taking a battery out of service, the electrolyte has not been withdrawn, the battery can be returned to service by adding water, if needed, to the cells and overcharging the battery until the specific gravity of the electrolyte has ceased to rise during a period of 5 hours.

If the battery has been standing without electrolyte, new wooden separators are installed and the cells then filled with electrolyte of 1.210 specific gravity. If the old electrolyte has been saved, only enough new electrolyte is added to replace any loss. The battery is then charged for 35 hours at the normal rate, or for a proportionately longer time at a lower rate. If the specific gravity of the electrolyte is low after the first charge, it should be restored to standard by the addition of acid.

31. Lead Burning.—In making joints between lead and lead, repairing tank linings, etc., solder cannot be used, because it is subject to attack and corrosion by acid. For such work,

a process called *lead burning* is employed, requiring a blowpipe with a flame produced by the admixture of hydrogen and air under pressure. Ordinary illuminating gas is sometimes used instead of hydrogen, but the hydrogen flame is hotter and more effective. In lead burning, no flux of any kind is used, but the surfaces to be joined are partly fused with the blowpipe and the space between is filled by melting down a strip of lead drop by drop.

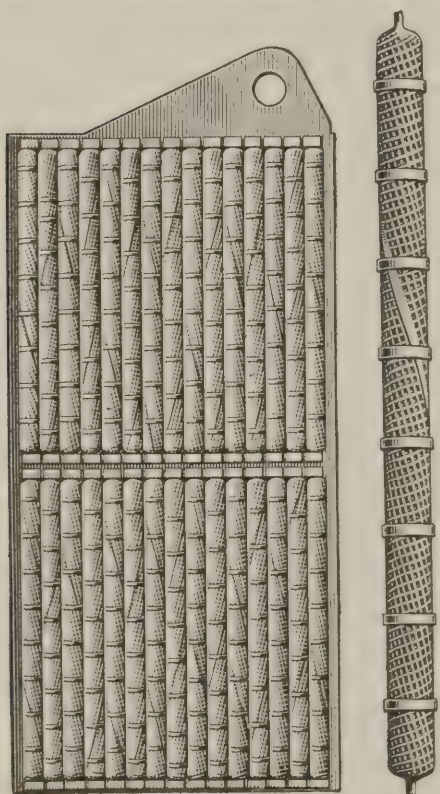
32. Capacity of Storage Batteries.—The *capacity* of a storage battery is usually stated in units called *ampere-hours.* An ampere-hour is a current of one ampere maintained for one hour; hence, the capacity of a battery in ampere-hours is found by multiplying the number of amperes of current delivered by the number of hours during which the current passes. For instance, a storage battery that is capable of discharging 5 amperes of current continuously for a period of 8 hours has a capacity of $5 \times 8 = 40$ ampere-hours; in like manner, one that will deliver a current of 10 amperes for a period of 12 hours has a capacity of 120 ampere-hours, etc. The *rate of discharge* of a battery is often referred to in terms of hours. In the examples just given, the batteries are said to be discharged at the 8- and 12-hour rates, respectively. The ampere-hour capacity varies with the rate of discharge, being less at high rates than at low rates. The term *efficiency* applies to the ratio of energy output to energy input. Under usual conditions, the efficiency of a battery that is fully charged and subsequently completely discharged, varies from 70 to 80 per cent. The output of a battery depends upon several variable characteristics of its make-up, each of which may cause an appreciable variation in its efficiency. Under favorable operating conditions, where the battery is only partly discharged and soon recharged, the efficiency may be over 90 per cent.

THE NICKEL-IRON-ALKALINE CELL

33. Plates.—The positive plate, Fig. 9 (*a*), of the nickel-iron cell consists of a number of hollow tubes, or pencils, of perforated steel, nickel-plated, supported vertically in a nickel-

plated steel grid. The pencils, Fig. 9 (*b*), are made of steel ribbon wound spirally with overlapping riveted seams, and are reinforced at intervals by steel bands. The active material consists of nickel peroxide and flake nickel tamped into the tube in alternate layers, the flake nickel being added to decrease the internal resistance.

The negative plate, Fig. 10, consists of rectangular pockets of perforated nickel-plated steel supported in a nickel-plated



(*a*) (*b*)

Fig. 9

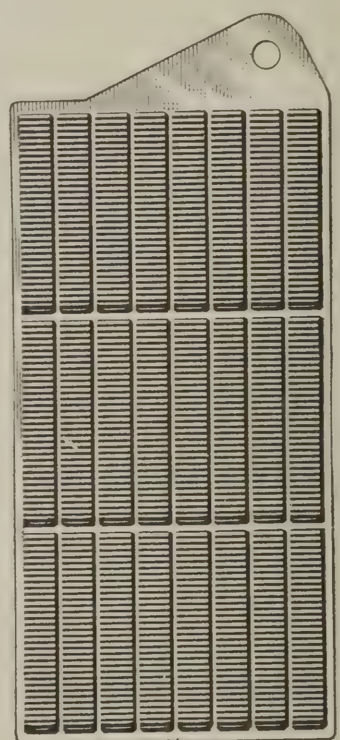


Fig. 10

steel grid, the pockets being filled with finely divided iron oxide, which is reduced to metallic iron by the initial charge.

34. Assembly.—As in the lead cell, the positive and negative plates of the nickel-iron cell alternate, with negatives outside, there being one more negative than positive plate. The plates of each cell are assembled into positive and negative groups by bolting the corresponding lugs together and to the terminal posts by means of steel connector rods with clamping

nuts at each end, the plate lugs being spaced apart by steel washers. All steel parts are nickel-plated. Fig. 11 shows the plates of one cell when assembled.

35. Separators and Electrolyte.—The plates are separated from each other by vertical strips of hard rubber, square in section, inserted with their vertical edges against the plates, as shown in Fig. 12, which is a view of a cell from above. Sheets of hard rubber are inserted between the outside negative plates and the jar, and hard rubber bridges *a*, Fig. 11, notched to receive the vertical edges of the plates, serve to separate these edges from the sides of the jar. The

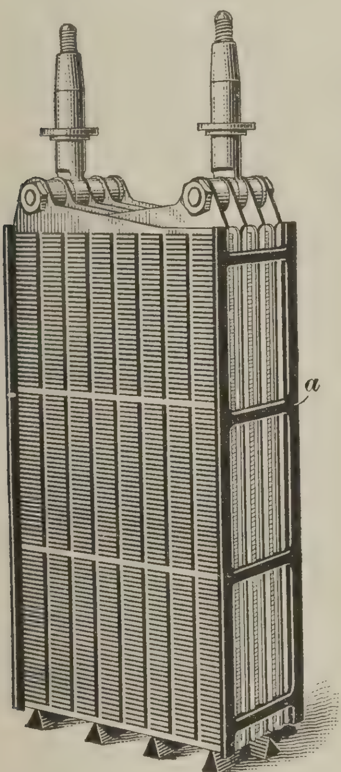


Fig. 11

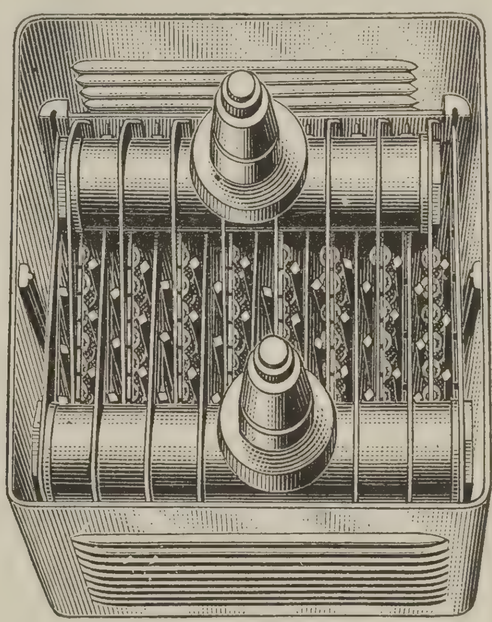


Fig. 12

plates rest on hard-rubber bridges on the bottom of the jar, as shown in Fig. 11.

The electrolyte is a dilute (21 per cent.) solution of potassium hydrate (caustic potash), specific gravity approximately 1.200. A small amount of lithia (lithium hydroxide) is added.

36. Container.—The container of the nickel-iron cell is a box made of nickel-plated sheet steel, corrugated to give added stiffness, the cover being welded on after the element

is in place. The two terminal posts *a* and *b*, Fig. 13, pass through circular openings provided with rubber bushings. Another opening in the cover, used for filling the cell, is closed by a spring cap containing a valve *c* that allows the gases to escape during charge, but excludes the external air.

37. Capacity.—The rated capacity of the nickel-iron cell is based on a 5-hour discharge rate. The actual capacity in ampere-hours, however, is but little affected by variation of discharge rate, provided no limit is set to the final voltage. In order to obtain maximum ampere-hour capacity at the higher rates, the final voltage must drop to a point too low for many classes of service.

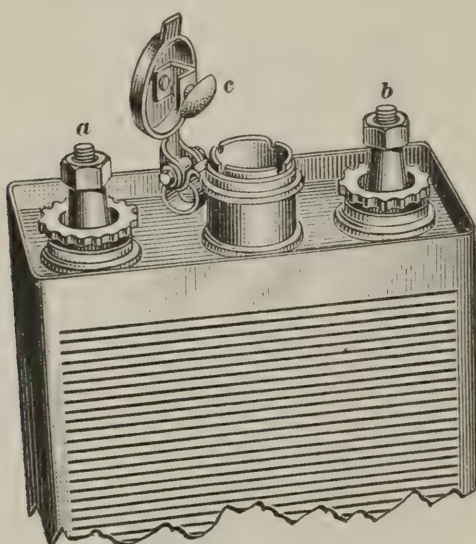


FIG. 13

Though the rated capacity is obtained by charging at the normal 5-hour rate for about 7 hours, it is possible, by giving the cells an excessive overcharge (16 hours at normal rate), to obtain on the subsequent discharge an increase in capacity of about 25 per cent. The excess is therefore obtained at a sacrifice in efficiency.

38. Voltage.—The open-circuit voltage of the nickel-iron cell is 1.5 approximately when fully charged and the average discharge voltage 1.2. After a substantial discharge, the open-circuit voltage is restored only very slowly, and never completely until a freshening charge has been given.

In Fig. 14 are curves that show charge and discharge voltages of the nickel-iron cell at normal rate. The discharge curve, as shown, is carried to .9 volt, though the normal-rate discharge is seldom carried below 1 volt in practice. The manufacturers recommend providing a charging voltage of 1.85 per cell.

39. Efficiency.—The efficiency of the nickel-iron cell is lower than that of the lead cell under similar conditions. Not only is the difference in voltage between charge and discharge proportionately greater in the nickel-iron cell, but the efficiency is low on account of the gassing that occurs during the entire charging period. An efficiency of 50 to 60 per cent. in commercial operation is about as high as can be expected, and this figure may be reduced if an attempt is made to utilize the maximum capacity of the battery.

40. Advantages and Applications.—The principal advantages of the nickel-iron cell are durability, mechanical ruggedness, and ability to withstand neglect and abuse without

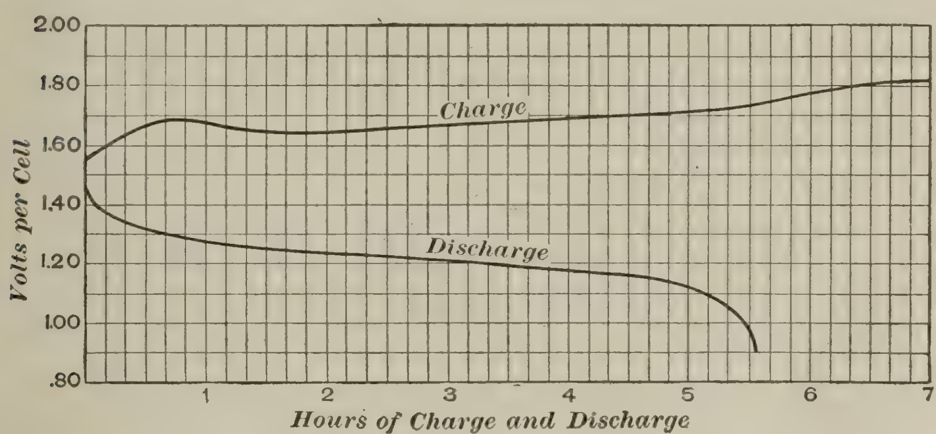


FIG. 14

injury. Life curves published by the manufacturers as a result of laboratory tests show a maximum of 1,100 complete cycles of charge and discharge. The cell is not injured by standing in a discharged condition, nor by excessive overcharge, provided excessive temperature is avoided. At low rates of discharge, the nickel-iron cell is much lighter than the lead cell for the same watt-hour output; but this difference in weight disappears as the rate of discharge increases, on account of the proportionately lower voltage of the nickel-iron cell. The Edison cell is, therefore, best adapted for service at low discharge rates where the cost of charging current is low, where light weight is important, and where indifferent care and attention are given. On the other hand, the nickel-iron cell is not

well adapted for high rates of discharge, nor for service in which the cost of charging current is high, nor where a battery must retain its charge for a long period of time without recharging.

41. Charging.—The state of charge of the nickel-iron cell cannot be determined by the density of the electrolyte, which does not change. Neither is the cell voltage or the amount of gassing a reliable guide. The only practicable method is to measure the output and input in ampere-hours, either by noting the rate in amperes and the time or by means of an ampere-hour meter. The manufacturers recommend a charge of 7 hours at normal rate after a discharge of 5 hours at the same rate, which is equivalent to 40 per cent. overcharge, in ampere-hours. The cell temperature should not be allowed to exceed 120° F.

The method of operation best adapted to the nickel-iron cell is that in which partial, or *boosting,* charges are given in the intervals between partial discharges. Boosting charges are particularly advantageous where the rate of discharge is sufficiently high to produce excessive polarization drop. The boosting charge quickly restores the cell voltage to normal, where otherwise it would remain abnormally low.

42. Changing Electrolyte.—The electrolyte in nickel-iron cells gradually deteriorates, owing to the absorption of carbonic-acid gas from the air. Deterioration, however, cannot be absolutely prevented, and although this gas does not permanently injure the plates, it reduces the capacity of the cells temporarily. About once in 6 months the electrolyte should be completely renewed.

Water that is to be used for filling the cells must be protected from exposure to the air for any considerable length of time, because water absorbs carbon dioxide (carbonic-acid gas) from the air. The local water supply, or even rainwater, which is very nearly pure, cannot safely be used for filling; distilled water protected from exposure to the air is generally necessary.

43. Special Precautions.—The containers of nickel-iron cells, being of metal, must be carefully insulated from each

other and must be kept clean. The wooden crates in which the cells are supported, as well as the sides and floor of the battery compartment, must be kept clean and dry for the same reason. If the insulation between cells becomes defective from any cause, a small leakage of current will, by electrolytic action, puncture the steel containers.

The nickel-iron cell is gassing more or less at all times, whether charging, discharging, or standing on open circuit. These gases (oxygen and hydrogen) produce an explosive mixture. Care must therefore be taken to guard against bringing an exposed flame or producing an electric spark in the vicinity of the cells, unless the ventilation is very thorough.

44. Repairs.—The covers of nickel-iron cells are welded in place after the cells are assembled. The plates cannot readily be removed from the containers, and whenever repairs are required it is necessary to return the cells to the factory for this purpose.

GENERAL OPERATING INSTRUCTIONS

45. Charging Storage Batteries.—Before a storage battery will deliver a current, it is necessary to bring its active materials to the proper condition for generating electricity by charging it, that is, by passing through it an electric current obtained from some outside source. The current used in charging a battery must be a direct current, as an alternating current would merely charge and discharge the battery because of the rapid reversals of current. After a battery is properly charged, it will deliver a direct current when connected in a closed circuit; the length of time that the current will pass depends on the ampere-hour capacity of the battery and the amperage of the current. The rate at which a storage battery will discharge depends on the resistance of the external circuit, and can be changed by varying the resistance.

46. Charging Through Resistors.—A charging resistor is connected as at *r*, Fig. 15, where the voltage of the charging source is greater than that required for the number of cells in series. The resistor in this case may be adjusted

to give any desired resistance within its capacity when connected in a circuit. In such cases, the voltage of the charging source should be slightly in excess of the voltage of the battery at the end of the charge; the resistor serves to reduce this voltage to that required at the beginning of the charge, and the resistance is gradually cut out as the charge proceeds, thus compensating for the increase of battery voltage.

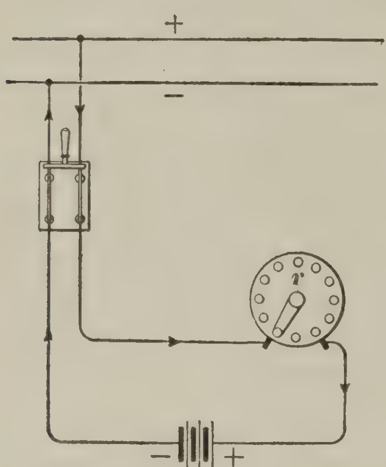


Fig. 15

47. Charging Through Lamps.—The group of lamps and the group of cells are connected in series across the line wires of the charging circuit. The voltage across the group of cells will be less than the line voltage because of the voltage expended in forcing current through the lamp bank. The current consumption of the lamps will then determine the charging current. Fig. 16 shows a method of connecting a battery to charge from a 110-volt circuit through five 110-volt, 16-candlepower, $\frac{1}{2}$-ampere lamps connected in parallel, the charging current being practically $5\times\frac{1}{2}=2\frac{1}{2}$ amperes. The charging current passes through the switch *a*, the right fuse *b*, the lamps, the battery *c*, the ammeter *d*, if one is used, the left fuse *b*, and switch *a*. The lamps may be connected in either lead to the battery. If, in the arrangement shown in Fig. 16, there are 25 cells in series, having a voltage between 55 and 65 while charging, the voltage across the lamps will be between 55 and 45, or about half the normal lamp voltage. Only half the normal amount of current will

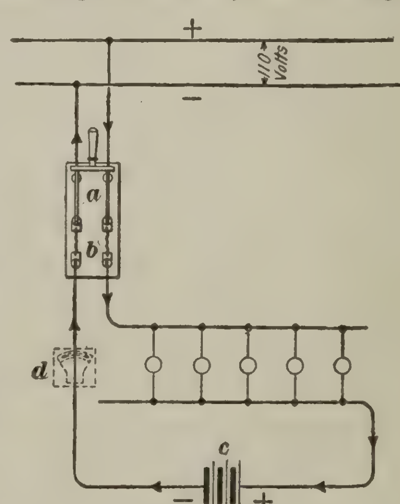


Fig. 16

then be transmitted through the lamps, provided their resistance remains constant. But the resistance of a carbon-filament lamp increases as the amount of current through it decreases, while the resistance of a tungsten filament decreases as the current is reduced, and allowance must be made for this. The charging current is best determined by connecting an ammeter in series in the circuit.

The approximate number of either tungsten-filament or carbon-filament lamps required for the charging lamp bank may be found by multiplying the charging rate in amperes by the line voltage and dividing the product by the watt consumption per lamp. For example, if 40-watt lamps are to be used, with a voltage of 110 and a charging current of 8 amperes, the result would be $\frac{8\times 110}{40}=\frac{880}{40}=22$ lamps. If the battery has a considerable number of cells in series, a few more lamps should be used, as the voltage across the lamp bank will be considerably less than 110 because of the opposing voltage of the battery.

48. Charging Panel.—A very well designed panel outfit, with switching and testing apparatus included, is shown by the diagram in Fig. 17. This small switchboard is particularly designed as one to be installed on ships, provision being made for charging a set of storage batteries from the direct-current supply, usually available on board steamships. Should the ship's power fail from any cause, the battery may be used to furnish power to operate the radio equipment, so that communication and the sending of distress signals may not be interrupted or prevented.

The six-pole double-throw switch *a* places batteries *b* and *c* on charge when closed to the right-hand position, and places them on discharge when the switch is closed to the left set of contacts. The two leads *d* which are connected to the radio apparatus are connected to the supply line as long as the switch is in its right-hand position. When the switch is to the left, these same leads receive energy from the two battery sections connected in series. As it is possible that the voltage of the

supply circuit may become reversed, it is desirable to provide a reversing switch *e* in supply circuit, so that by simply throwing the blades over to the other points, the voltage applied to the battery will be of the correct polarity.

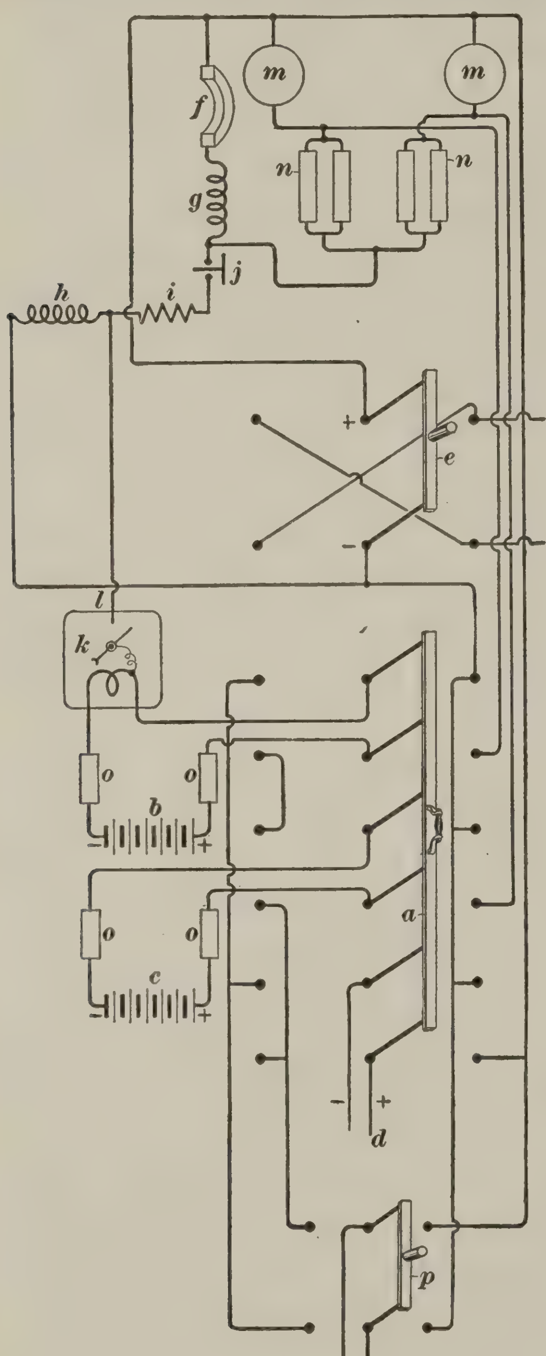


Fig. 17

A circuit-breaker *f* is connected into the charging circuit and is provided with an overload trip coil *g* and a low-voltage release coil *h*. In the circuit with the latter coil is a resistor *i* and an auxiliary circuit-opening switch *j*. The switch *j* is mechanically connected to the circuit-breaker so as to open when the circuit-breaker opens. The object of the resistor *i* is to prevent an excessive current when the coil *h* is short-circuited by the contact hand of the ampere-hour meter *k* as described later. When switch *j* is opened, the delicate contact point *l* in the ampere-hour meter *k* is not required to break any current in case the hand of the instrument moves away from its fully charged position.

49. The coil *g* carries the total current in the charging circuit and if this current becomes too large for any reason, as, for example, on account of a short circuit, the action of the coil *g* is to lift a plunger which trips open the contacts of the circuit-breaker *f*.

The coil *h* surrounds a plunger *j* which when released by the interruption of current in the coil *h* will trip open the circuit-breaker *f*. The interruption of the current in the coil *h* may take place from either of two causes: First, the ship's power may fail, causing the voltage across the coil to drop to such a low point that the coil can no longer hold the plunger. The dropping of the plunger opens the circuit-breaker *f* and prevents the batteries from discharging energy back into the main supply circuit, a condition which might easily happen were not this arrangement provided. Second, the hand of the ampere-hour meter returning to the position it occupies when the battery is fully charged, short-circuits the coil *h*, through contact *l* and the top blade of switch *a*, when this switch is closed to its right-hand position. The stopping of the current through coil *h* causes it to drop the plunger *j* which will trip open the circuit-breaker *f*, thereby stopping the battery charge except for the trickle charge explained later. This second condition takes place only when the battery is fully charged, as indicated by the ampere-hour meter.

50. An ampere-hour meter *k* records the number of ampere-hours furnished by the battery on discharge. If the watt-hours are desired it is only necessary to multiply the reading by the voltage. An indicating hand on the meter rotates in a clockwise direction as current is being taken from the battery. When the battery is on charge, the current through the meter is reversed and the hand rotates in a counter-clockwise direction. Assuming that the battery was fully charged, then drawing a certain number of ampere-hours from the battery will cause the meter to give a corresponding reading. Charging the battery will cause the needle of the meter to move back to its former position, thereby indicating that as much energy has been returned to the battery as was supplied

by it. When the indicating hand reaches its fully charged position it makes an electrical contact at point *l* which completes the path around coil *h* as previously mentioned.

51. Except during discharge the batteries are always on a trickle charge through the two lamps *m* of rather high resistance. This small charging current compensates for any internal losses in the batteries and by keeping them fully charged insures their being able to deliver a full discharge at any time. The resistance units *n* are in series with the batteries when on regular charge, and carry the charging current. The number of resistance units to be used depends on the size of the batteries, as a larger charging current is required by a large battery than by a relatively small one.

52. Fuses located at *o* in the battery leads are installed to protect the circuits and wiring from excessive current, either from the charging source or from the batteries when they are on discharge. A two-pole double-throw switch *p* transmits electrical energy to an emergency lighting circuit which includes a few lamps that are located at important points in the ship. When in its right-hand position, energy is taken from the ship's power, but in case of emergency the switch may be closed to the other contacts, when energy will be taken from the battery for providing a small amount of illumination at strategic points. A voltmeter, which is not shown in this illustration, may be connected by a special switching device and several leads to any one of several connected points. Pressing a push button which forms a part of the voltmeter circuit, causes it to give a reading of the voltage at the desired point.

53. A front view of the panel, showing the arrangement of the various switches and measuring devices, is given in Fig. 18, with the lettering references of the previous figure maintained. In considering the position of the switches it should be understood that Fig. 17 is merely a conventional wiring diagram, but the actual assembly of switches and devices is as indicated in Fig. 18. The six-pole, double-throw switch *a* is shown in a position to operate the radio equipment from the storage bat-

teries. When thrown to the left connections are made for charging the batteries, which are not shown in Fig. 18 but may be placed in any convenient and protected location in the vicinity of the panel. Leads *d* to the radio apparatus, Fig. 17, are installed on the rear of the panel and connected to the two lower blades of the switch *a*, Fig. 18. The reversing switch *e* is thrown so as to connect the polarity of the ship's power correctly to charge the batteries. The circuit-breaker *f* is flanked on one side at *g* by the overload release coil, and at *h* by the low-voltage release coil. The protective resistor and auxiliary opening switch are mounted on the rear of the panel. The ampere-hour meter *k* carries the contact point *l*, Fig. 17, which is not shown in Fig. 18.

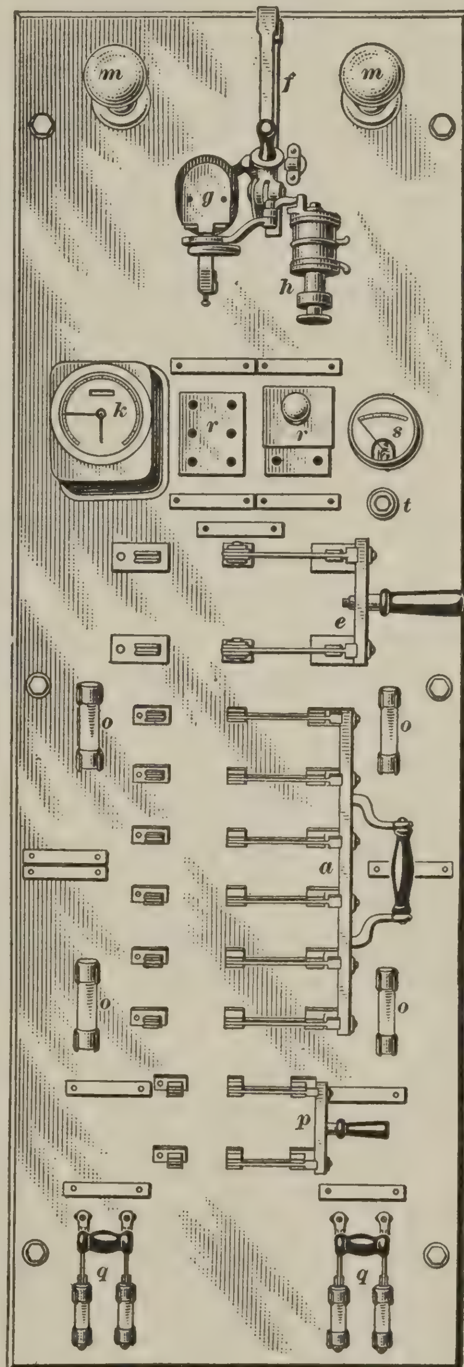


FIG. 18

54. The two lamps *m*, Fig. 18, are the ones through which current passes for the trickle charge. The resistors, which determine the value of the charging current, are mounted behind the panel, both for convenience and appearance. The fuses *o* are the ones in the battery circuit, the leads to the batteries being taken from terminals provided on the rear of the panel. The double-

pole, double-throw switch p is thrown so as to utilize the batteries to supply current to the lights necessary in an emergency; switches q with their fuses are also used to connect and protect local lighting circuits.

The special switching device r, through several leads, connects the voltmeter s to various points of the panel circuits. A voltage reading may be obtained when the voltmeter circuit is closed by pressing on the push-button t. All this apparatus is mounted on a panel board the chief purpose of which is to act as a support for the equipment. Slate and marble are often used as panels, as they are good insulators, are strong, and present an attractive appearance.

THERMOELECTRIC COUPLES

55. Development of Thermoelectric Force.—A **thermoelectric force** is developed by the contact of two dissimilar metals and it varies not only with the kinds of metals and the physical condition of each but also with their temperature.

A **thermoelectric couple** is a combination of metals joined together that is capable of producing with proper heat

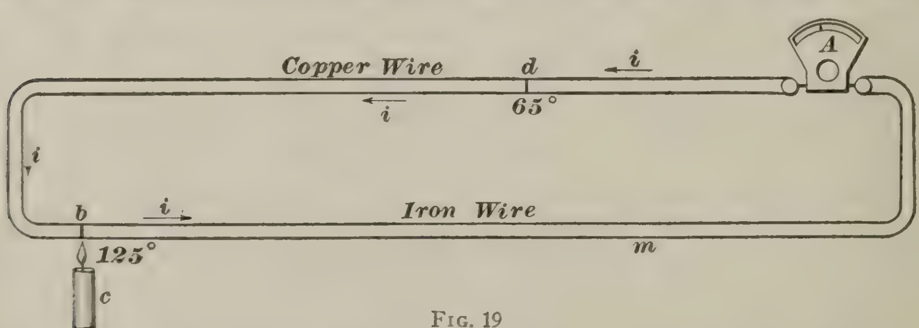


Fig. 19

treatment a thermoelectric force. That a voltage is developed by heating a contact of two dissimilar metals may be shown in the following way: Solder or otherwise join together a copper and an iron wire, as shown at d and b, Fig. 19, and include somewhere in the circuit an instrument A that will detect or measure an electric current and also indicate its direction. If the junction b is heated to a temperature of 125° and the

junction *d* is kept at the temperature of the room, say 65°, then the instrument *A* will show that electricity flows from the copper wire across the hot junction *b* to the iron wire, through the iron wire and the instrument *A* to the junction *d*, then across this junction to the copper wire, as indicated by the small arrows *i*.

If the junction *b* is cooled below the other parts of the circuit, the flow of electricity will be in the opposite direction, that is, from the iron through the contact *b* to the copper wire, etc., that is, in the opposite direction to the arrows *i*. In either case energy in the form of heat is converted into energy in the form of electricity. This phenomenon is known as the *Seebeck effect,* after the man who discovered it.

56. In general, the thermoelectromotive force is larger in proportion as the difference of temperature increases. The current produced in a given circuit will be proportional to the difference in temperature between the two junctions, provided the mean temperature of the two junctions has remained the same or nearly the same.

If two dissimilar substances are joined at one point and the two free ends connected by a third substance, for instance, a long copper wire, the thermoelectromotive force developed will be exactly the same as if the two substances were connected directly together without the third substance, provided the two free ends that are joined to the copper are at the same temperature.

57. Use of Thermoelectric Currents.—On account of the small value of thermoelectric currents, they have not been of great practical value, except in determining high and very low temperatures, but they often become a source of great annoyance and error in accurate measurements with delicate instruments. The chief use of a thermoelectric couple in radio work is in the measurement of a high-frequency current. The thermoelectric couple is placed very near to or in contact with a conductor that is heated by the radio current. The current that is thus established in the thermoelectric couple is measured by a suitable direct-current instrument.

ALTERNATORS

ALTERNATING ELECTROMOTIVE FORCE

GENERAL THEORY

58. The **alternator** is one of the simplest machines for the transfer of mechanical energy into electrical energy. The alternator generates an alternating electromotive force by what is commonly called *electromagnetic induction*. When an electric conductor is moved across a magnetic flux, or a magnetic flux cuts across a conductor, an electromotive force is induced, or generated, in the conductor. Most of the modern alternators have revolving magnets which produce a revolving flux, and an electromotive force is generated by the action of the flux cutting across conductors mounted on a stationary frame. In some cases the *active* conductors are rotated past stationary magnets, thereby cutting magnetic flux. In either case, the stationary frame is called the *stator*, and the rotating element is called the *rotor*.

No electromotive force will be generated if both the flux and the conductor are stationary, or if the motion of the conductor or the flux is such that the conductor does not cut across the flux or the flux cut across the conductor.

59. Direction of the Electromotive Force.—The conductor *a b*, Fig. 20 (*a*), is moved toward the right across the magnetic flux of the permanent magnet, as indicated by the full-line horizontal arrow. The direction of the inducing flux is downwards, as shown by the arrowheads on the dotted vertical lines. An electromotive force is set up in the conductor in such a direction that the current established will always produce a conductor flux that agrees in direction with the inducing flux on the side of the conductor that first comes in contact

with the inducing flux and is opposite in direction on the other side of the conductor. This fact holds true whether the conductor or the flux is the moving element. The direction of the conductor flux is indicated by the arrowheads on the curved lines surrounding *a b*. The direction of the electromotive force, as well as that of the current in this case, is from *a* to *b* in the conductor, as indicated by the arrowheads on the circuit wires. The flux is more dense ahead of the conductor than

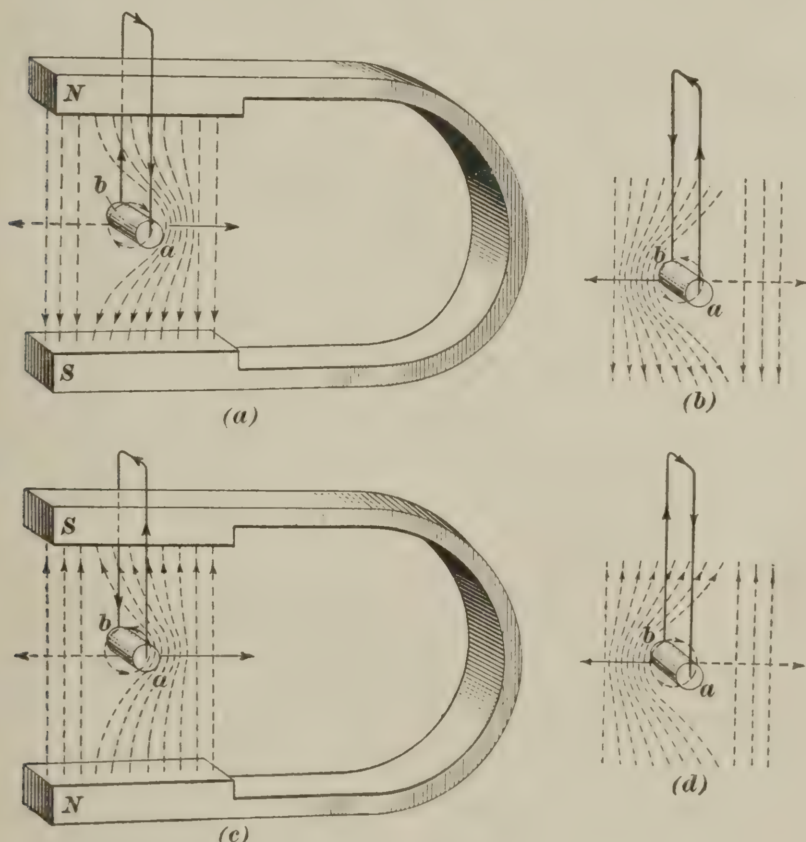


FIG. 20

behind it because of the relation between the direction of the inducing flux and that of the conductor flux.

The direction of the induced electromotive force in any case where the relative direction of the movement of the flux and of the conductor is known may be determined by considering which side of the conductors has the denser flux. The direction of the circular conductor flux on that side agrees with the direction of the inducing flux, and the direction of the induced

electromotive force is determined from the relation of the conductor current and its flux, as is explained in a previous Section.

60. The conductor *a b*, Fig. 20 (*b*), is moved toward the left and the induced electromotive force is from *b* to *a*. In (*c*) a conductor is represented as moving to the right in a field in which the direction of the flux is vertically upwards. The direction of the induced electromotive force is from *b* to *a*. In (*d*) the conductor is moved toward the left in the same field, and the direction of the induced electromotive force is from *a* to *b*.

It should be noted that when either the direction of the motion of the conductor or the direction of the flux is reversed, the direction of the electromotive force is reversed, as in views (*a*) and (*b*) or in (*a*) and (*c*); but, when both the direction of the flux and the direction of the motion of the conductor are reversed, the direction of the induced electromotive force remains unchanged, as in views (*a*) and (*d*) or in (*b*) and (*c*). The straight dotted arrows relate to the direction of the movement of the conductor when considered as a motor conductor.

REVOLVING-FIELD ALTERNATOR

61. Fig. 21 (*a*) shows an elementary *alternator* having a two-pole, *revolving-field* rotor *a* mounted within a stator *b*. The rotor is assumed to revolve in a clockwise direction as indicated by the long curved arrows. The active windings, in which alternating electromotive forces are generated, are distributed in slots in the inner cylindrical surface of the stator, the stator and its windings being known as the *armature*. For simplicity only one coil of a single turn is shown, consisting of active conductors *c* and *d* and connecting wires on the front and back of the stator. Connections on the rear of the machine are indicated by dotted lines.

The *exciter e* is a small direct-current generator, such as is described later, often mounted on the end of the rotor shaft and turning with it. In other cases the exciter is sepa-

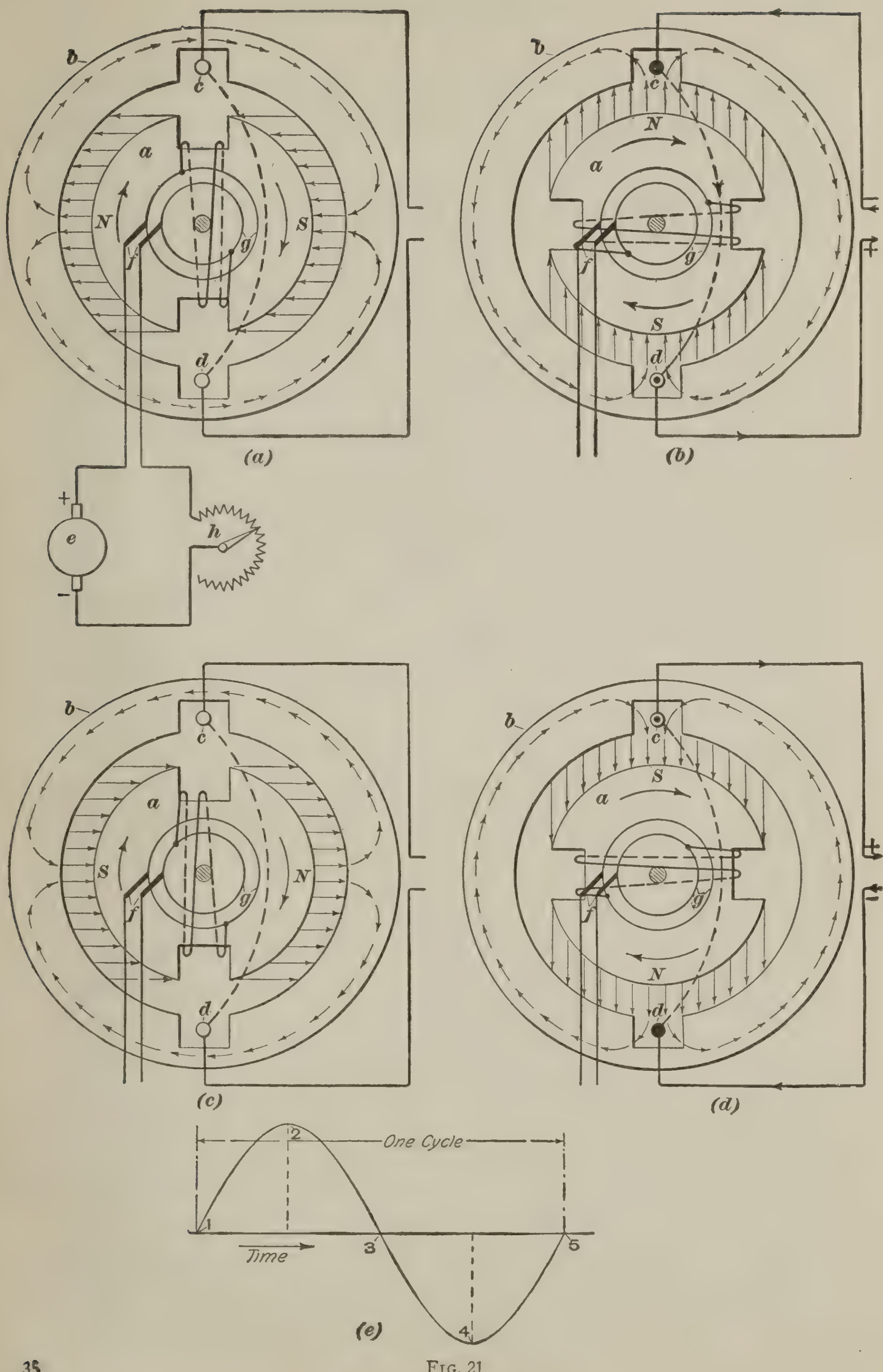


FIG. 21

rately mounted and driven by a belt from the alternator shaft, or an independent direct-current supply system may be used for exciting several alternators.

62. Direct current for exciting the field-magnet winding, which with the core forms an electromagnet with poles of special shape, is transmitted to the rotor from the exciter through two stationary brushes *f* and two slip rings *g*, the latter mounted on and revolving with the rotor. The polarity of the field magnets and the general distribution of the fluxes in the magnetic circuits of the machine are indicated in Fig. 21 (*a*), which represents the magnetic field flux as uniformly distributed in the air gap. In actual electrical machines the flux distribution is usually not so uniform. In order to avoid confusion, only two lines of force and their directions are shown in the stator by the short-curved arrows, although there are many shorter loops on each side of the machine, and in fact in all parts of the stator.

63. As the rotor turns, the flux cuts across the stationary active conductors on the stator and an electromotive force is generated in them except when the rotor is in the position shown in views (*a*) and (*c*). At these positions the fluxes are parallel to horizontal planes through conductors *c* and *d*, and no electromotive force is established as the fluxes do not cut across either *c* or *d*.

With the rotor in the positions indicated in views (*b*) and (*d*), the fluxes from the poles are cutting across the conductors at maximum rate, therefore the maximum values of electromotive forces are generated; but it should be noted that in (*b*) the flux from the north pole cuts across conductor *c* and in (*d*) the flux entering the south pole cuts across this same conductor. The electromotive forces induced in these two positions are in opposite directions, as the electromotive force must always agree with the principles concerning the relative motion of the conductor and flux given previously.

64. The conductors *c* and *d* are so placed and connected that the electromotive forces generated in them act in unison, or series, to send current through the coil and the external

circuit when a load is connected to the terminals of the generator. In actual alternators many conductors are coiled together and connected in series to give a higher voltage than would be generated by a coil of one single turn. Other coils are ordinarily distributed around the stator, thus considerably increasing the output of the machine.

65. Fig. 21 (*e*) indicates very closely the rise and fall of an alternating electromotive force or current established by an alternator of the type shown. The vertical distances between the base line *1–5* and points *1*, *2*, *3*, *4*, and *5* on the curve correspond to the values of the electromotive forces generated at positions of the rotor shown in (*a*), (*b*), (*c*), and (*d*), point *5* referring also to the position shown in (*a*). The direction of the current in the coil and the external circuit at position (*b*) is assumed, simply for purposes of comparison, to be positive as represented by the curve at point *2* above the base line in view (*e*). A negative value could have been assigned to this electromotive force if desired.

66. Starting with point *1* of view (*e*) and with the position of the rotor as shown in (*a*), the field flux begins to cut the armature conductors *c* and *d* at an angle as the rotor is turned. Due to the relative direction of the flux and the position of the conductor, the rate of cutting the lines of force of the flux is low, as indicated by the portion of the curve in (*e*) just to the right of point *1*. As rotation of the rotor continues the lines of force of the flux cut across the conductors at a higher rate and the generated electromotive force increases at a corresponding rate. This increase will continue until the rotor has reached the position shown in (*b*), when the electromotive force will have attained its maximum value as shown by point *2* in (*e*).

As rotation continues from position (*b*), the rate at which the lines of force of the flux cut across the conductors gradually decreases until position (*c*) is reached, and the electromotive force generated during this movement will be as shown by the curve in (*e*) from point *2* to *3*. This portion of the wave from *1* to *3* represents an *alternation*.

Continued motion of the rotor will produce an alternation similar to the one just generated, but of opposite polarity. In the preceding case the flux from a north pole cuts conductor *c* while now flux from a south pole cuts that conductor. According to the principles shown in Fig. 20, the generated electromotive force is in the opposite direction to that just produced. This will give the wave shown in Fig. 21 (*e*) from point *3* through negative maximum at point *4*, and back to zero at point *5*. It should be noted that at both points *1* and *5* the electrical conditions are the same, and the position of the rotor is shown in view (*a*). Another complete revolution of the rotor would produce another curve exactly similar to (*e*).

67. A complete set of positive and negative values of electromotive force or current in any conductor is called a **cycle.** The curve shown in (*e*) represents a cycle, which is made up of two alternations. The frequency, as has been defined, is the number of cycles through which the electromotive force or current passes in one second. The shape of the curve generated under above conditions is a sine curve, and is so represented in view (*e*). The current being directly dependent upon the voltage, varies according to the same laws, and would also be represented by a sine wave.

68. The machine shown in Fig. 21 is known as a *single-phase alternator,* as it generates a single wave of current. The current generated by such a machine and represented as a single curve such as shown in (*e*), is called a *single-phase current*. In other electrical work machines are used which generate two-, or three-, or occasionally six-phase currents. The principle of their operation is quite similar to that already described.

69. The value of the electromotive force generated by an alternator depends upon the speed of the rotor, the number of conductors in series and their distribution between any two terminals, and the total flux from all poles. In practice it is usually undesirable to increase the voltage of the alternator by increasing the speed of the rotor. Increasing the strength of the

current in the coils of an electromagnet increases the amount of flux set up by the magnet. The rheostat *h* in Fig. 21 (*a*), which contains an adjustable resistance, controls the current through the field windings of the rotor. The current furnished by the exciter *e* may be increased by decreasing the resistance of *h*, or decreased by increasing the resistance that is active in the rheostat. With an increase of field current, the field flux is increased and as a result the generated electromotive force is also greater on account of the larger number of lines of force which cut the armature conductors.

ELEMENTARY REVOLVING-ARMATURE ALTERNATOR

70. An elementary type of *revolving-armature alternator* is shown in Fig. 22. A soft-iron armature core *a* on a shaft *b* carries on its convex surface conductors at *c* and *d* and revolves between magnetic poles *N* and *S* so that the conductors cut the flux of the magnetic poles. Electromotive forces are generated in these *active conductors,* which are connected by other conductors to the slip rings *e* and *f*.

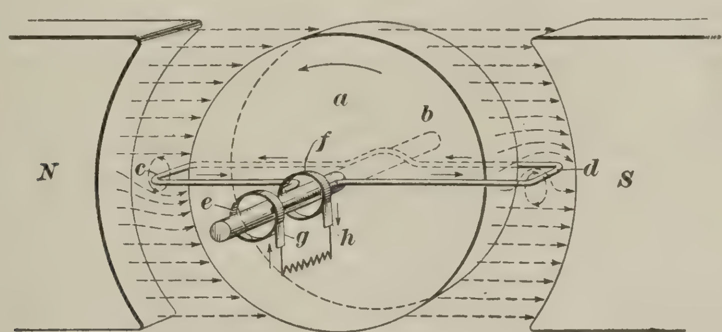


Fig. 22

Stationary brushes *g* and *h,* which bear on the rings, serve to connect the armature conductors with an external circuit.

With a counter-clockwise direction of armature rotation and the flux in the direction indicated, the electromotive force in *c* is toward the front, and in *d* toward the rear of the armature. The principles of electromagnetic induction, as explained in connection with Fig. 20, should be applied to the conditions of Fig. 22. The two conductors are so connected

across the back of the armature that the two electromotive forces act in series to force current through the circuit. The shape of the current wave will be a sine curve similar to that shown in Fig. 21 (*e*).

FREQUENCIES

71. Alternating-current frequencies may be roughly divided into three general classes or groups. Frequencies of 60 and 25 cycles per second are practically the only ones used in American commercial alternating-current machines. Alternators operating at 500 to 900 cycles are quite common in certain kinds of radio work. For another branch of radio work, alternators giving 100,000 or even 200,000 cycles per second are used. The special uses of these frequencies are considered under their proper headings.

The types of alternators which have been described are especially applicable to the generation of 60- and 25-cycle voltages.

THE 500-CYCLE REVOLVING-ARMATURE ALTERNATOR

72. A section through the revolving armature and stationary field frame of an alternator used in the generation of 500-cycle alternating voltage is shown in Fig. 23 (*a*). The armature of the same machine is shown separately in view (*b*). It will be seen that there are many coils *a* on the armature *b* of this machine. The slip rings at *c* serve to make electrical connection to the external circuit by means of brushes, which in the assembled machine bear on, and make contact with, the slip rings. View (*c*) shows the iron field frame *d* with the pole projections carrying the field coils *e*. The field coils are separately excited by direct current. The large number of poles combined with the high rotative speed of the armature serves to produce a voltage of rather high frequency.

73. The magnetic circuit of the alternator shown in Fig. 23 is of rather unusual construction, in that there are twice as many field poles as there are field coils. For explanation, a simple electromagnet in the shape of a horseshoe may be con-

sidered. If equal windings are placed on both legs and energized by a current, poles will be formed near the ends of

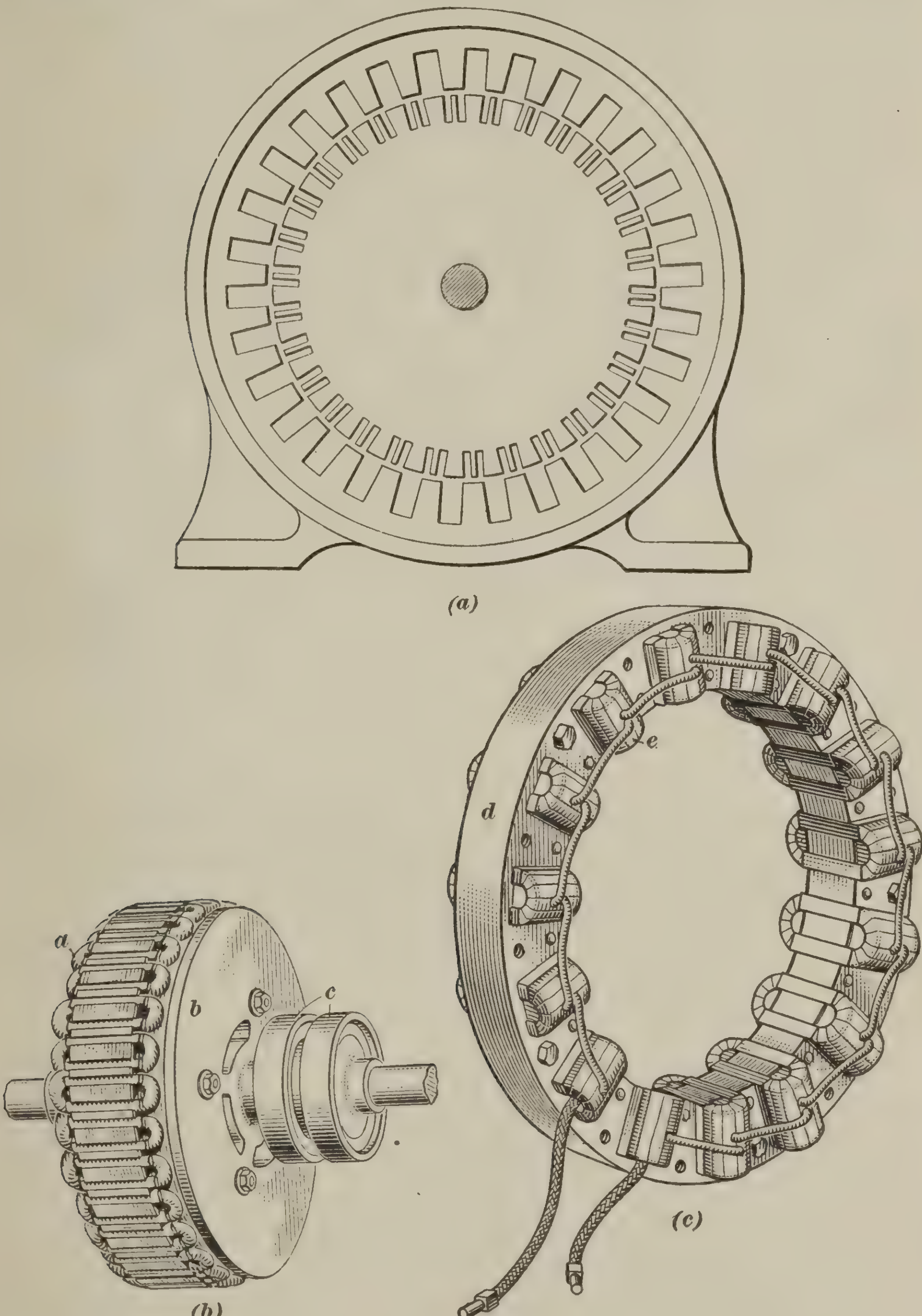


FIG. 23

the core when the coils are energized. If only one coil is energized by the same current, poles will be established as

before, but as there is now only one-half as many active turns of wire, the strength of the poles will be approximately one-half their former value. If all the winding were placed on one leg of the core, the magnetic flux produced when the coil is energized would be only slightly less than that originally established by the two separate windings.

In the case of the alternator shown in Fig. 23 this principle is applied, as every alternate pole is energized through the magnetizing action of the windings on adjacent poles, a feature which seemed desirable in the design of this machine. A **consequent pole** is formed when the flux through the pole is due to the combined magnetizing effects of the two field windings of two adjacent magnetic circuits.

In actual machines the magnetic field is usually produced by electromagnets excited by windings on the pole projections. The windings are usually equally divided among all the poles, but practically the same results are obtained by placing larger windings on one-half of the poles as mentioned above. In the alternator shown in Fig. 23, the arrangement of placing the field windings on alternate poles saves considerable space.

PRINCIPLE OF THE INDUCTOR ALTERNATOR

74. Magnetism may be established through iron much more readily than through air. Consequently when iron is placed in the air gap of a magnetic circuit, the number of lines of force will be greatly increased. Withdrawing the iron will cause the flux to decrease to its former value. As changes of flux take place through the whole of the magnetic circuit, an electromotive force will be induced in a coil surrounding the magnetic circuit by what is known as *induction.* If the iron is periodically inserted into and withdrawn from the magnetic field, an alternating current will be established in the coil surrounding the magnetic circuit.

Such, briefly, is the principle of the *inductor alternator,* in which both the field frame and armature are stationary. Changes in the number of lines of force cutting the armature coils are produced by rapidly passing sections of iron through

portions of the magnetic circuit. The lengths of the iron sections are such as to close the magnetic circuit, except for small mechanical clearances, between moving parts. Large variations in the number of lines of force, evident as pulsations in the flux, generate alternating voltages at rather high frequency.

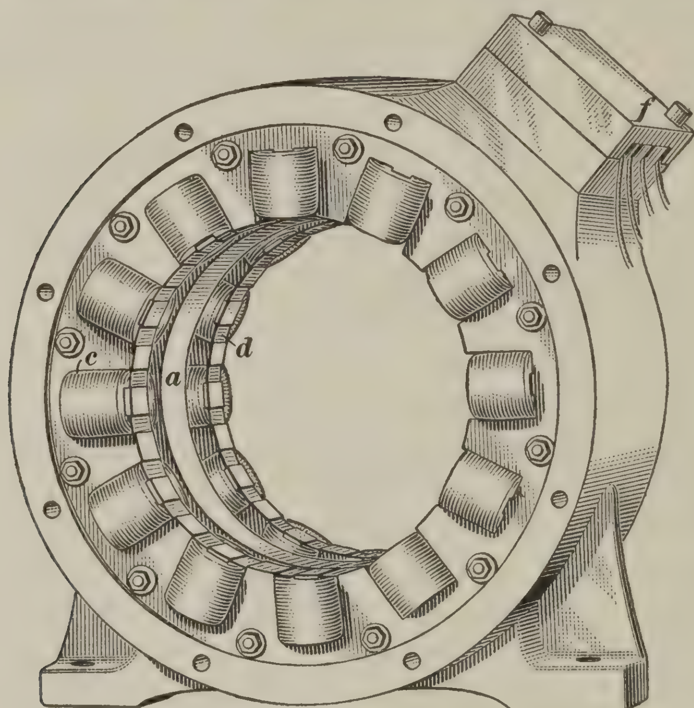
THE 500-CYCLE INDUCTOR ALTERNATOR

75. Fig. 24 shows a type of 500-cycle alternator made by the Crocker-Wheeler Company. The field winding *a*, view (*a*), consists of a large stationary coil and is in a plane at right angles, or perpendicular, to the shaft. The flux produced when the coil is energized passes from one end of the rotor *b*, view (*b*), to the other end, and returns through the outer shell of the stator, thus forming a closed magnetic loop. The armature windings are in two groups of twelve coils each, one group being shown at *c* and the other at *d*, view (*a*). The coils are mounted on inwardly projecting sections of iron and are all connected in series, thus giving a high generated electromotive force. The magnetic flux follows the iron of the twelve teeth to their ends in preference to passing through the air spaces between the teeth. When the projections on the rotor are directly opposite the armature projections, maximum flux will be established, as the magnetic circuit is nearly all iron. When rotation brings the long air space, or gap, opposite an armature projection, the flux is considerably decreased because of the increased length of the air path in the magnetic circuit. The constantly varying field flux induces an alternating voltage of high frequency in the armature coils.

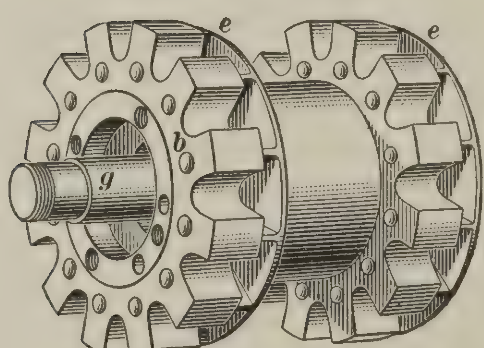
76. The projections on both the rotor and armature are made up of thin sheets of iron insulated from each other by shellac, forming what are known as *laminations*. This tends to prevent excessive heating which would be caused by local currents established in the iron if the projections were of solid iron.

The disks *e*, view (*b*), with the radial blades act as fans and help keep a current of air circulating over the armature and field windings. All current-carrying conductors heat to some

extent due to energy losses, and if not properly cooled, their insulation may be injured by overheating. This is especially true of windings which are partly enclosed, in which case



(a)



(b)

Fig. 24

some means of insuring a circulation of cooling air must be provided.

This alternator does not require slip rings, as external connections may be made directly to the stationary windings, leads

being brought out at *f*. *End plates* support bearings for the shaft *g*, and are shown and described more completely under the discussion of motor-generator sets.

THE 100,000-CYCLE INDUCTOR ALTERNATOR

77. Alternators have been constructed which furnish 100,000- or in some cases 200,000-cycle alternating voltages. For the generation of voltages at these excessively high frequencies, special construction and design features must be followed. As the inductor alternator may be made without rotating windings, which is a distinct advantage in securing mechanical strength and ruggedness, that type is commonly used. Several machines of the inductor type designed for very high frequencies have been developed.

The *Alexanderson alternator,* so named from its designer, has been successfully operated for the generation of voltages at 100,000 and 200,000 cycles. The field and armature windings are stationary and properly mounted with respect to the magnetic circuit. A rotor of magnetic material with numerous radial slots cut near its outer edge, produces many changes in the flux of the magnetic circuit per revolution; thereby generating in the stationary armature coils a voltage of very high frequency.

78. The general arrangement of the elementary parts of an Alexanderson alternator is shown in Fig. 25 (*a*), which represents a radial section from the center of the shaft to the outside of the machine. The magnetic circuit is energized by the current in two coils *a*, each extending completely around the inside circumference of the outer frame of the machine. In some machines when the stator frame is in two parts a slightly different arrangement of field coils has been developed. The field coils receive exciting current from an external direct-current source. The armature windings located as shown at *b* are wound, as represented in view (*b*), in zigzag formation in open slots around the whole circumference of the machine. This type of construction is necessary in view of the large

number of active conductors (in some cases 600) which must be placed in a rather limited space. The rotor *c*, view (*a*), a

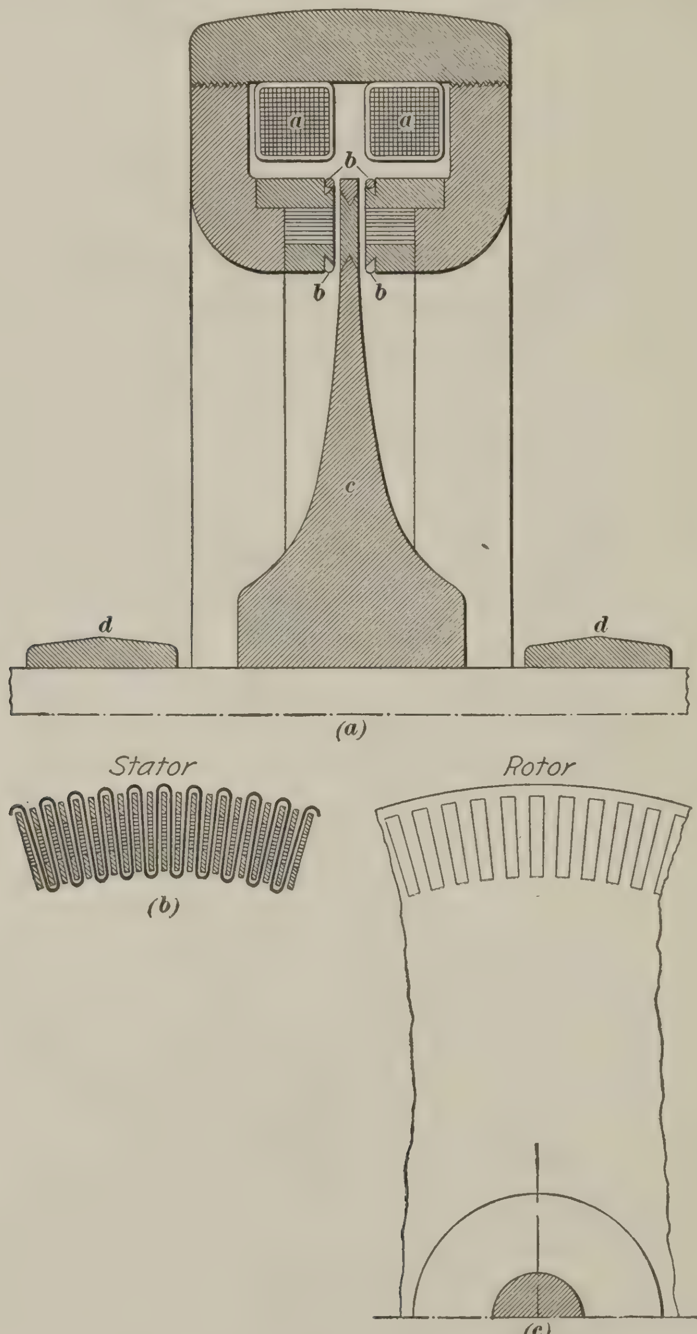


FIG. 25

portion of which is shown in view (*c*), is made of very high grade steel, carefully machined and balanced. Radial slots are

cut near the outer edge of the rotor, and filled with some non-magnetic material. This makes the face of the rotor smooth, which, at the high rotative speed, is very essential in preventing excessive windage losses.

The magnetic flux, tending, as always, to follow the path of least opposition, will be tufted or bunched through the spokes of the rotor. The non-magnetic filling of the rotor slots between the spokes will act practically the same as air so far as its influence on the field flux is concerned. As changes in the number of lines of force occur with the passing of the rotor teeth or spokes, the recurring increase and decrease of field flux must necessarily cut the armature conductors and generate voltages in them. The conductors are so spaced that as the flux is increasing near one conductor, it is decreasing near the one next to it, and so on around the armature. Thus the electromotive forces generated by the different conductors can be combined to give the desired value of voltage. As the changes in the values of the magnetic fluxes affecting the armature conductors are made very rapidly, a high-frequency voltage is generated. In some machines the alternator armature windings are connected to a transformer and the voltage for the wireless system taken from the high-voltage coils of this device.

79. The rotor bearings at *d,* Fig. 25 (*a*), are lubricated by oil, supplied by a positive-feed oiling system. It is imperative that oil be kept supplied to the bearings, otherwise they would soon burn out.

The portion of the magnetic circuit near the armature conductors is made up of laminated iron to prevent local currents being set up by the rapid changes of flux. In larger capacity machines these local currents may cause considerable heating. In some machines of this type, cooling is effected by water circulating through pipes placed near the armature conductors.

These machines are usually driven by high-speed alternating-current or direct-current motors equipped with special apparatus to give them constant speed with fluctuating load. An enclosed gearing is usually employed between the motor and

alternator to give a high rotative speed to the alternator rotor. The speed of the rotor is usually at least 2,000 revolutions per minute, and in some cases is as high as 20,000 revolutions per minute. When a rotor with several hundred spokes is used, it is quite possible to generate an alternating voltage of exceedingly high frequency.

GENERATION OF ELECTRO-MOTIVE FORCE
(PART 2)

DIRECT-CURRENT MACHINES

DIRECT-CURRENT GENERATORS

COMMUTATION

1. Elementary Generator.—A **direct-current generator,** or **dynamo,** is a device for converting mechanical energy into electrical energy in such manner as to produce a flow of electricity in one direction through the external circuit that is connected to the machine. An elementary direct-current generator is shown in Fig. 1. The armature, indicated at *a*, is supported within the space between the poles *N* and *S* by the shaft *b*. When the generator is in action, voltages are generated in armature conductors *c* and *d* since these conductors cut up or down across the lines of force between the poles. The windings of the field coils are not indicated in Fig. 1.

The voltage, or electromotive force, generated in the armature conductors is an alternating one, since each conductor cuts down and then up across the same group of lines of force, thus causing a reversal in the direction of its generated electromotive force. The alternating voltage is changed to direct voltage, as far as the external circuit is concerned, by a rectifying device called a *commutator*. The action of a commutator in producing a direct voltage from an alternating one is known as *commutation*.

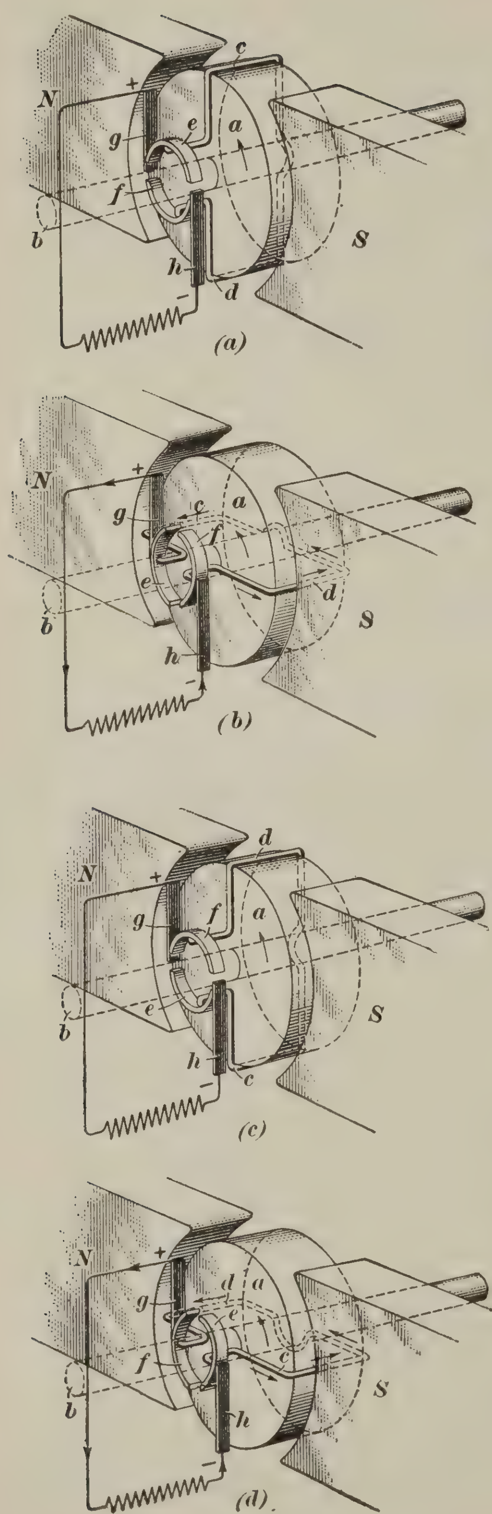


Fig. 1

2. The simple commutator shown in Fig. 1 consists of two semicircular bars *e* and *f* mounted near, but not touching, each other on the shaft *b* and insulated from it. Conductor *c* is connected to bar *e* and conductor *d* to bar *f*. The brushes *g* and *h* serve to connect the external circuit with the commutator. As the shaft turns counterclockwise, brush *g*, view (*a*), makes contact with bar *e*, and brush *h* with bar *f*.

The electromotive force generated in the turn, as soon as the conductors start to cut across the lines of force, causes a flow of electricity out through the bar *e*, the *positive brush g*, the external circuit, and into the armature by means of the *negative brush h* and bar *f*. At the end of the first quarter revolution the positions of the armature conductors *c* and *d*, the positions of the commutator bars, and the direction of the current are as indicated in (*b*). At the end of the second quarter, the conductors *c* and *d* are generating no electromotive force and the bars are just reversing their con-

nections to the brushes, as indicated in (*c*). At this time there is no current in the circuit. During the third and fourth quarters, the bar *f*, view (*d*), is in contact with the positive brush *g* and bar *e* is in contact with the negative brush *h*. The direction of current in conductors *c* and *d* is indicated by the arrows. At the end of the fourth quarter, the conductors are again in the positions shown in (*a*), and the commutator bars are about to reverse their connections with the brushes.

As indicated by the arrows near conductors *c* and *d*, views (*b*) and (*d*), the direction of current in each conductor is reversed because the direction of motion of the conductors with reference to the flux is changed; but commutation serves to keep the current uniform in direction in the external circuit.

3. The alternating voltage generated in a conductor on the armature would be represented by a sine curve if the flux were uniformly distributed in the air gap. The commutator serves to produce in the external circuit a pulsating electromotive force which in turn produces a pulsating direct current of the shape shown in Fig. 2. The voltage or current in the external circuit starts at zero, rises to a maximum value, decreases to zero, and repeats this action as long as the circuit is active, the current being in the positive direction at all times with respect to the reference line *a b*.

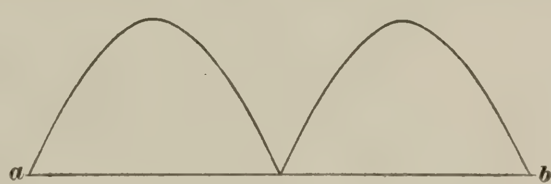


FIG. 2

A current changing in value in the general manner indicated in Fig. 2 is called a *pulsating current*. The term, as ordinarily employed, refers to a direct current that varies in magnitude through a regular series of changes between maximum and minimum values; the minimum value may or may not be zero.

4. Armature With Several Coils.—The variations of the current, as indicated in Fig. 2, are due to the armature having only a single turn of wire. In an actual armature, there are many coils and commutator bars. The conductors of a few coils are passing through positions in which little or

no electromotive force is generated in them, and their connections to the brushes are then reversed; but there are always a number of coils connected in series in the two or more parallel paths between the positive and negative sets of brushes. Therefore, the direct electromotive force impressed on the external circuit does not fall to zero, as indicated in Fig. 2, but assumes a nearly constant value for all positions of the armature conductors during a revolution. The action of a coil of several turns connected in series is identical with that of a single turn, except that the electromotive force is increased in proportion to the number of turns in the coil.

GENERATOR PARTS

5. The purpose of the electromagnets that form the field magnets of an electric generator is to establish a magnetic flux. Some types of small direct-current generators have only two pole pieces, and these are known as **bipolar generators.** In some very small generators, called *magnetos*, the exciting magnetic flux is furnished by one or more permanent magnets, and in such a case no windings are placed on the field magnets.

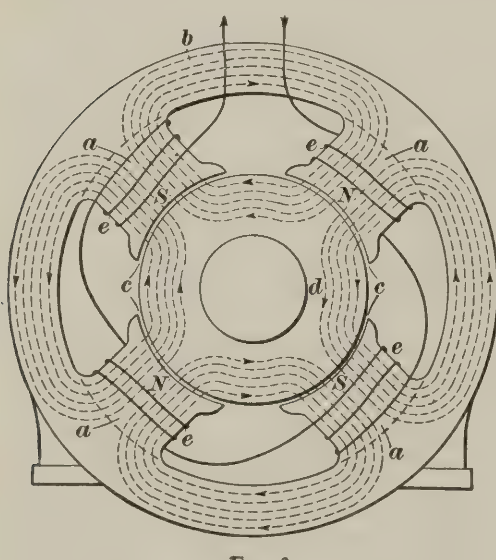


Fig. 3

6. The dotted lines, Fig. 3, indicate the magnetic circuits of the field-magnet frame and armature core of a four-pole generator. The *field-magnet cores*, or *pole pieces*, are shown at *a*, and the *field frame*, or *yoke*, at *b*. The broadened ends of the pole pieces are called *pole shoes*, and the surfaces of the shoes near the *air gaps c* between the pole pieces and the *armature core d* are called *pole faces*. The *field coils*, or *magnetizing coils*, are shown at *e*.

The field coils, field-magnet cores, pole shoes, and the yoke, taken collectively, are called the *field of the machine.* The field-magnet cores, pole shoes, air gaps, armature core, and field yoke, taken collectively, form the *magnetic circuits of the machine.*

When the current in the exciting coils is in the direction indicated by the arrowheads, the polarity of the pole faces is as indicated by the letters N and S and the paths of the magnetic fluxes are as indicated by the dotted lines. The field frame, field-magnet cores, pole shoes, and the armature core are made of very soft iron or of steel.

METHODS OF FIELD EXCITATION

7. Separately Excited Generator.—Generators may be classified according to the method employed to *energize,* or *excite,* the field coils. In a *separately excited generator,* the current for energizing the field coils is provided from a source external to the generator. The connections of both the armature and the field coils of such a generator are shown in Fig. 4. The exciting coils a are placed on the field-magnet cores and connected to a battery or to another direct-current generator. Positive brushes $+b$ and negative brushes $-b$ bear on the commutator c and serve to rectify the electromotive force generated in the moving armature conductors and to impress it on the external circuit d. There is no electrical connection between the exciting circuit for the field magnets and the armature circuit.

The value of the generated electromotive force may be varied by changing the speed of the armature or by changing the value of the magnetic flux. The latter change may be effected by means of a variable resistance e in the field circuit or by changing the electromotive force causing the exciting current.

8. Shunt Generator.—Another type of machine is called a **self-exciting shunt generator,** or simply a *shunt generator,* from the fact that the exciting current for the field coils is provided by the generator itself. The exciting circuit

is connected across the brushes on the armature and is in *shunt,* or parallel, with the external circuit of the generator. A shunt, in its broad sense, refers to a side path; when applied to an electric circuit, it refers to a side path between two points already connected.

The connections of a shunt generator are indicated in Fig. 5. The resistance device *a,* called a *field rheostat,* is included in

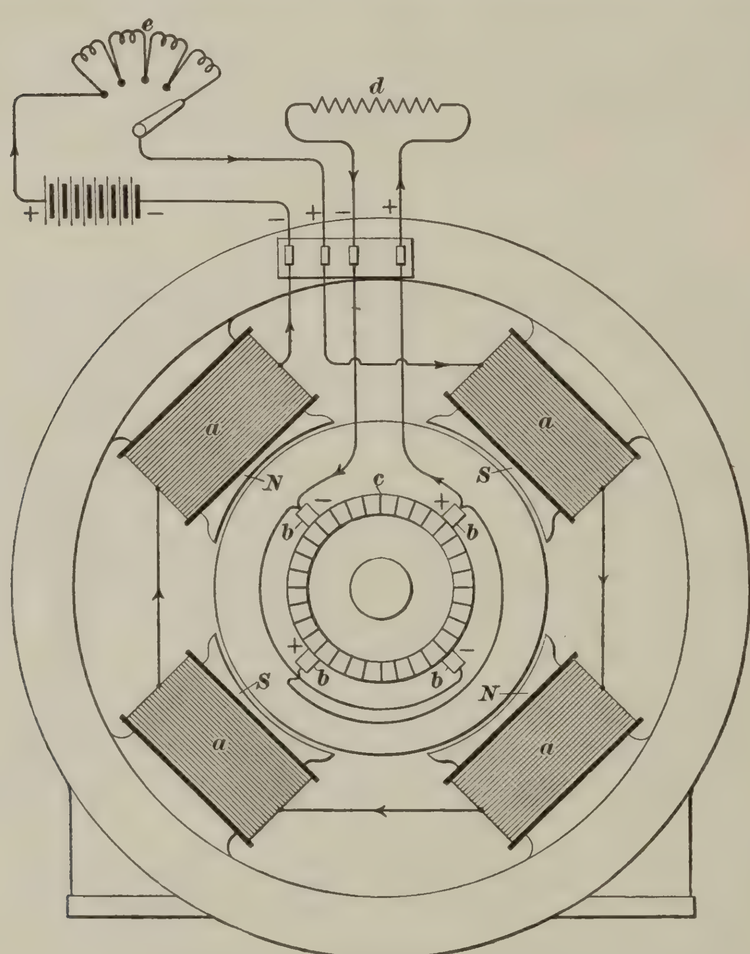


FIG. 4

the exciting circuit and serves to adjust the exciting current and thus regulate the electromotive force generated by the armature conductors.

The field coils of a shunt generator are formed of many turns of fine copper wire and the individual coils are connected

in series, but this group of coils is connected in shunt with the armature. The resistance of the exciting circuit is high and only a very small part of the current from the armature is required to energize the field magnets.

9. Building Up a Magnetic Flux.—In order that a self-exciting machine may start to generate, some residual

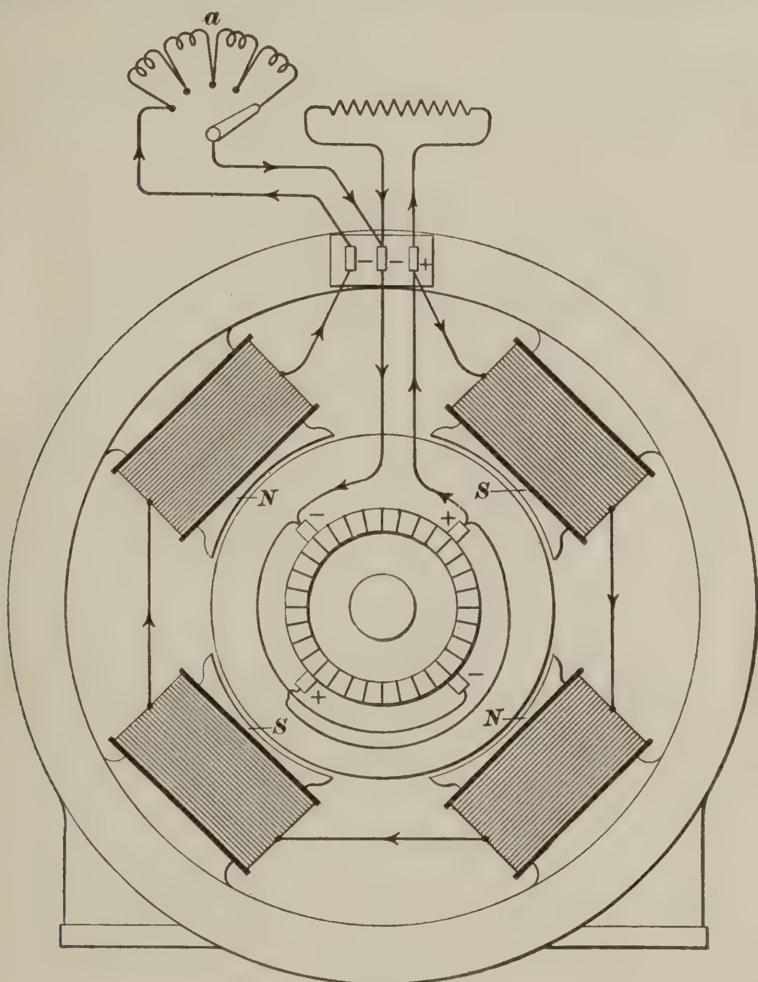


FIG. 5

magnetism is required in the field of the generator. The frame of even a new machine is often slightly magnetized, but if it is not magnetized sufficiently, or if it is of incorrect polarity, the field coils may be separately excited temporarily from another generator or from a few cells of battery. The shunt circuit is then disconnected from the separate source and connected to the brushes of its own armature.

The slight electromotive force generated by the armature will establish a current in the exciting circuit. This will increase the inducing flux, resulting in an increase of electromotive force and further building up of the exciting current and the flux. A point of balance of the electrical and magnetic effects is finally obtained where the generated electromotive force and the exciting current become constant for existing

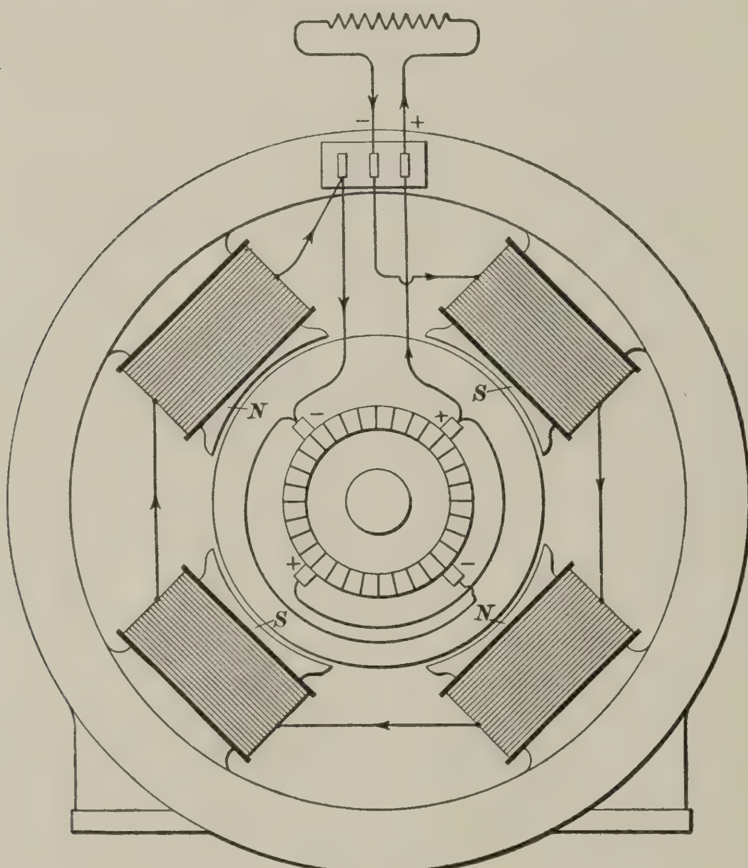


Fig. 6

conditions of operation. The operation of setting up the magnetic flux is termed *picking up,* or *building up,* the flux.

10. Series Generator.—Another type of self-exciting machine is the series generator. The exciting coils are connected in series with the armature and the external circuit, as indicated in Fig. 6. No electromotive force, except the slight value due to residual magnetism, is generated in the armature

unless the external circuit is closed and a current is established throughout the circuit. The electromotive force generated depends on the value of the current in the circuit, which consists of the field coils, the armature, and the external circuit. The field coils on this type of machine are formed of a conductor of comparatively large sectional area, and each coil has comparatively few turns.

11. Compound Generator.—Automatic regulation of the electromotive force of a generator may be effected by a

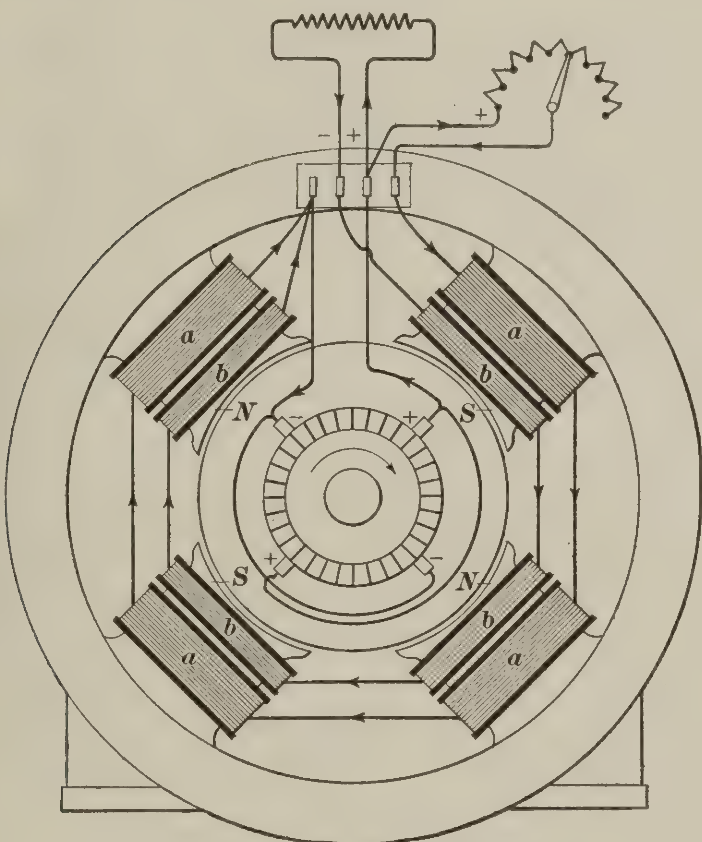


Fig. 7

combination of shunt- and series-field coils forming part of a **compound-wound generator,** connections for which are shown in Fig. 7. The shunt coils are shown at *a* and the series coils, at *b*.

In a generator as usually connected, the magnetizing forces of the shunt coils *a* and the series coils *b* act in unison to set

up fluxes in the cores of the main field magnets. When the generator is running, but is not connected to the external circuit, the magnetizing forces of the shunt coils *a* produce the flux of the magnetic field of the machine. When the external circuit is closed, current is established in the main series coils *b* and the fluxes in the cores of the main field magnets are increased and a higher electromotive force is generated. If the load on the generator increases still further, the exciting current through the series coils increases, thus building up the fluxes in the magnet cores and causing a higher electromotive force to be generated. This higher electromotive force is desired because of the increased drop in volts necessary to force the larger load current through the armature, the external circuit, and the series-field coils. The generated electromotive force may be adjusted by means of the field rheostat in the circuit of the shunt-field coils.

12. Compounding.—The preceding method of regulating the electromotive force of the generator is called *compounding*. A machine is *flat-compounded* when the magnetizing force of the series coils is adjusted so that the voltage at the generator terminals remains practically constant for all loads. It is said to be *overcompounded* when the voltage at the terminals rises with the load so that some distant point on the external circuit may have nearly constant voltage for all loads.

In an *accumulatively compounded generator,* the shunt coils and series coils are so connected to their respective circuits that they act in unison to establish the inducing flux and thus to increase the generated electromotive force as the load increases.

In a *differentially compounded generator,* the connections of the shunt and series coils are such that the flux of the series coils acts in opposition to, or *bucks,* that of the shunt coils. Generators of this kind are used in automobiles and to a limited extent in wireless work. If the speed of a variable-speed generator exceeds a given value, the electromotive force at the terminals does not increase, because of the bucking effect of the series coils.

DIRECT-CURRENT MOTORS

DEVELOPMENT AND DIRECTION OF TURNING FORCE

13. Motor Action of Conductor Flux.—A *motor* may be defined as a machine for converting electrical energy into mechanical energy. The turning effort, or *torque,* which maintains rotation of the armature, is established by the inter-

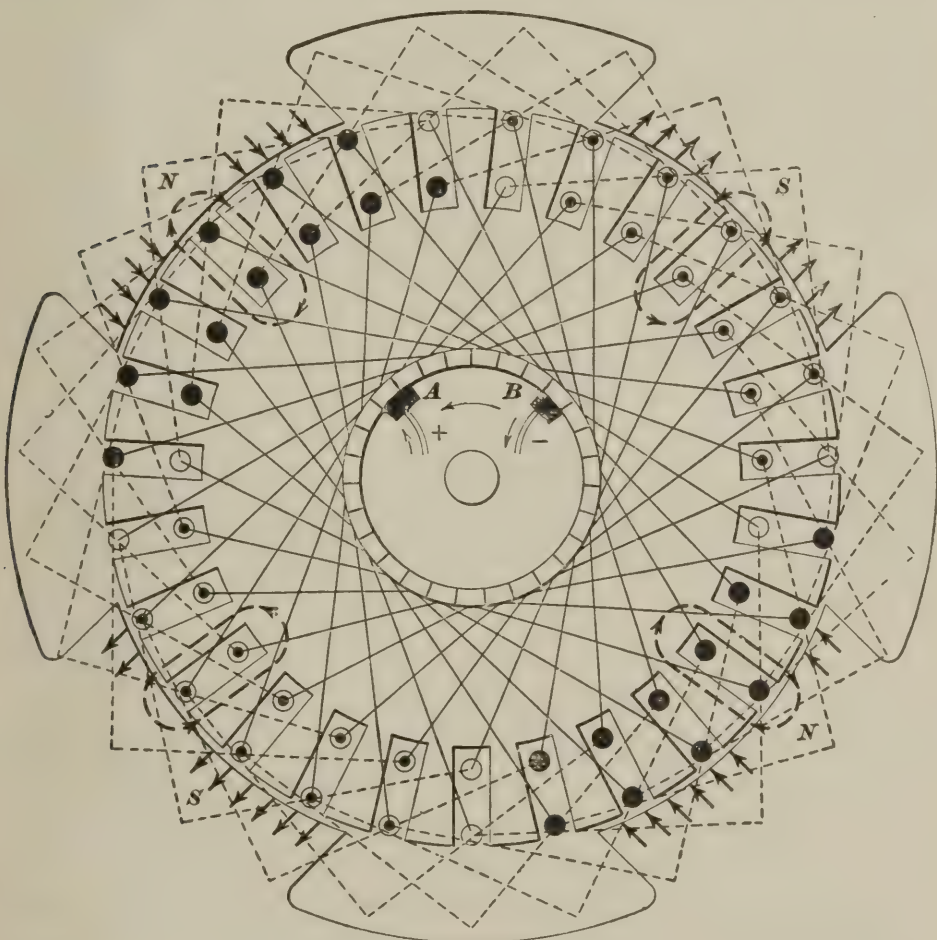


Fig. 8

action of the fluxes of the field magnets and the fluxes set up by the currents in the armature conductors. While the torque for each conductor is usually small, the torque for the whole armature consisting of many conductors may be large.

Fig. 8 shows one arrangement of conductors on an armature intended for a four-pole motor The active conductors, indicated by small circles, lie in slots in the armature core and are connected across the back of the core by wires indicated by dotted lines and to the commutator at the front of the core by wires indicated by solid lines. One-turn coils are shown, but usually a coil consists of a number of turns. A black circle indicates that the current in the conductor is away from the observer and a dotted circle that the current is toward the observer. White circles indicate little or no current because of commutation. Arrows near the pole faces indicate the direction of the field flux, and a loop with arrowheads drawn around one pair of armature conductors opposite each pole face indicates the paths of the flux set up by current in these conductors. To avoid confusion of lines, only a few paths for conductor flux are shown. The denser flux on the side of each conductor, where the directions of the conductor and field fluxes agree, tends to move all conductors so as to cause counter-clockwise rotation of the armature, as indicated by the curved arrow near the brushes A and B. The direction of motor action is also indicated by the straight dotted arrows in the group of sketches used in the discussion of the direction of the electromotive force generated in a conductor, in *Generation of Electromotive Force,* Part 1.

14. As the armature rotates, successive commutator bars slide under the brushes so as to reverse the direction of current in each conductor while the conductor is passing through the neutral space between the tips of adjacent pole pieces. The actions occurring at the commutator of a direct-current motor are exactly the reverse of those occurring in a direct-current generator commutator. Direct current comes to the motor commutator but is *rectified,* or *commutated,* into alternating current before reaching the armature conductors. The commutator serves to make the necessary current reversals, so that at all times the conductors adjacent to north poles carry current in one direction and the conductors adjacent to south poles carry current in the opposite direction, as indicated in

Fig. 8. The reaction between the flux of the poles and the conductor flux thus maintains the torque that keeps the armature in motion.

15. Relation of Generator and Motor Rotation. If a machine that has been operating as a shunt-wound generator is operated as a shunt-wound motor, the polarity of the circuit wires and the connections between the circuit and the machine being unchanged, the armature will rotate as a motor in the same direction as it did as a generator. Current now passes into the armature at the positive motor brushes, which are the same as the generator positive brushes. This causes a reversal of the direction of the current in the armature windings. The direction of the flux around a motor conductor near a north pole is opposite to that around a similarly placed generator conductor. The polarity of the pole pieces remains unchanged, because each end of the field-coil circuit is connected to a circuit wire of the same polarity as before. As far as magnetic interaction between field flux and conductor flux is concerned, the motor armature would rotate in the opposite direction from that of the generator armature, but it must be remembered that the generator armature is driven by a steam engine or other prime mover in a direction against this magnetic attraction, therefore the armature of the motor or of the generator will rotate in the same direction under the assumed conditions.

16. Reversal of Rotation.—If the current in either the field coils or the armature of a direct-current motor is reversed, the direction of rotation will be reversed; but if the current in both the field coils and the armature be reversed, the direction of motion will remain unchanged. A series motor will, therefore, run in the same direction, whatever the direction of the current through the machine as a whole. Reversing the line connections to the terminals of a series motor simply reverses the current through both the armature circuit and the field-coil circuit and does not change the direction of rotation. In order to reverse a series motor, either the armature terminals must be interchanged, so as to reverse the current through the arma-

ture only, or the field-coil terminals must be interchanged so as to reverse the current through the field-coil circuit only.

17. Motor Classification.—According to field winding, all direct-current motors are in three classes, namely, *shunt, series,* and *compound,* where these terms imply the same type of field-coil connections as were given in the discussion of the subject of direct-current generators. Shunt-wound motors start and operate with current input proportional to the torque, or turning effort, and run at practically constant speed at all loads. The current input to a series motor varies less than directly proportional to the torque and the speed varies widely with varying load. For example, at twice full-load torque, a shunt motor requires approximately twice full-load current and operates at only a trifle below its full-load speed, while a series motor requires considerably less than twice full-load current, but operates at much below full-load speed. Compound-wound motors have characteristics intermediate between those of shunt and series motors, resembling most closely the one that its predominating field winding most nearly resembles.

OPERATION OF DIRECT-CURRENT MACHINES

18. Inspection.—Direct-current generators and motors have many features in common; in fact, they are sometimes used interchangeably. A brief consideration of the operation and care of direct-current machines will apply to both generators and motors. Dynamo-electric machines and all devices connected with their operation or regulation should be kept scrupulously clean. No copper or carbon dust, dirt, grease, or oil should be allowed to remain on any part of the machine. Each part should be systematically examined, and cleaned, or repaired if necessary, at regular intervals. Connections should not be allowed to come loose, thereby producing a possible source of serious trouble.

19. Heating of the Armature.—An armature should run without undue heating; if it heats so as to smoke or give off an odor, the machine should be stopped at once and the

cause of the heating located and the trouble remedied. Heating may be caused by damp insulation, which, as a general rule, is shown by steaming, and may be remedied by baking the armature in an oven. *Overloads,* that is, loads greater than the rating of the machine, tend to heat the armature excessively, due to no fault of the machine.

If, instead of the whole armature running hot, the heat is confined to one or two coils, there is probably a *short circuit* either in a coil or between the two commutator bars to which the ends of the coil connect. If a short-circuited coil is run in a fully excited field, it will soon burn out. Repair of the defective coil should be made before using the machine again. By an *open circuit* in the armature is meant a break in one of the armature wires or its connections. Excessive current may burn off one of the wires or a bruise of some kind may nick a wire so that the normal load, or perhaps less, burns it off. This condition would be manifested by a slightly decreased output, and an inspection would probably locate it and suggest a method of repair.

20. Care of the Commutator.—The commutator is usually made of copper bars insulated from each other by thin strips of mica or mica composition. Brushes of carbon or in some cases copper, press on the commutator and serve to conduct current from the commutator to the external circuit. A moderate amount of sparking at the commutator is not very objectionable, but if it becomes sufficient in amount or in duration to blacken or roughen the commutator bars, the cause should be located and the fault corrected. Numerous small white sparks, evenly distributed along the edge of the brush and producing no distinguishable noise, usually work little injury.

Too large a load on the machine will often cause sparking, which in many cases may be lessened by shifting the brushes. In any case, the brushes should be so located that they reverse the connections to the armature conductors when they are cutting minimum flux. If the brushes are in good condition, make good contact, and are properly set, very little sparking

should be evident. Large sparks under such conditions would tend to indicate trouble with the armature. In some cases the commutator does not wear down smoothly and will require resurfacing either by fine sandpaper or by machining. Emery paper must not be used on the brushes or the commutator, as emery is a conductor and may cause short circuits between adjacent commutator bars. Moreover, particles of emery sticking to the face of the brush, being more gritty than sand, will scratch the commutator.

21. Field Coils and Connections.—The field coils are stationary, are usually well protected, and are not apt to cause a great deal of trouble. In installation, or assembly, the field windings may be connected incorrectly, but the proper connections for correct polarity of the pole pieces can be easily found experimentally.

The magnetic circuit of the generator may lose its residual magnetism, in which case it is probable that the armature voltage will not build up, or if it does, it is apt to be wrong for the proper direction of rotation. In either case, the machine should be shut down, and the field circuit disconnected. A low voltage, taken from the circuit of a direct-current generator or from a battery consisting of a few primary or secondary cells, is applied to the terminals of the field-coil circuit. The positive terminal of the source is connected to what should be the positive terminal of the field circuit and the corresponding negative terminals also connected. The current will set up a flux in the magnetic circuit of the generator and when the exciting circuit is opened, a residual magnetism of proper polarity should be established. The positive terminal of the field circuit should now be connected to the positive brush and the negative terminal of the field circuit to the negative brush. The armature should be driven at full normal speed and in the proper direction to cause the brushes assumed to be positive to be really so.

An *open* in the field circuit of either a generator or a motor may cause serious trouble. Frequent inspection and tightening of terminals will usually prevent this trouble.

22. Grounds.—The armature or field windings may become grounded on the armature core or on the frame of the machine. This condition should be corrected when found. Grounds are apt to cause considerable loss of power, and will constitute a short circuit if the windings are grounded at two or more points. The frame is often grounded intentionally by means of a high resistance in order to prevent the possibility of shock to any one coming in contact with the frame. The high resistance may under some conditions limit the current should one of the windings become grounded. The high resistance between the frame and ground permits any static charges, such as are caused by the friction of the belt on the pulley, to be conducted to the ground.

MOTOR AND GENERATOR COMBINATIONS

MOTOR-GENERATOR SETS

GENERAL PRINCIPLES AND USES

23. A *motor-generator set* is a combination of a motor coupled to one or more generators. The machines are connected by mechanical means and may be mounted on one base, but the armature windings with their corresponding field windings are entirely distinct. They may be merely two commercial machines whose shafts are connected by a coupling, or, for compactness, they may be of special design with both armatures mounted on a short shaft supported by one bearing at each end.

Motor-generator sets are commonly used for the following purposes: to change alternating current to direct current, or vice versa; to change direct current from one voltage to another; and to change alternating current at one frequency to alternating current at some other frequency. These changes are in some cases necessary, for example, where electricity of one voltage or frequency is available, but some other value is

required. The motor may be designed to operate satisfactorily on the available source of electricity and the generator may be designed to furnish current which will meet the particular requirements, such as high-frequency current for radio use.

SIMPLE MOTOR-GENERATOR SET

24. In its simplest form the motor-generator consists of a shunt-wound, direct-current motor driving an alternator excited by the same direct-current supply. Fig. 9 shows such a combination with a motor *a* driving the alternator *b*, which is of the revolving-field type. Rheostats *c* and *d* serve to regulate the amount of current through the motor field *e* and alternator

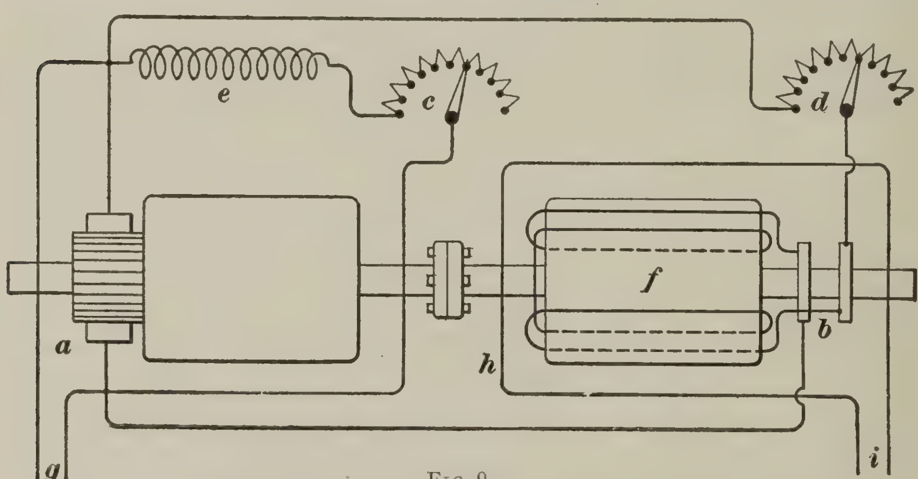


FIG. 9

field *f*, respectively. Direct current is supplied to the motor through leads *g*, and alternating current is taken from the alternator armature, of which only one turn *h* is indicated, by means of leads or terminals *i*. The frequency of the alternating current will depend upon the design of the alternator and the speed of rotation.

25. When used in radio work the alternator must operate under conditions which fluctuate from no load to full load with manipulation of the sending key. These large variations of output cause sudden changes in the amount of power required and tend to cause appreciable changes in the motor speed. To secure more uniform speed, it is desirable to use a

compound-wound motor whose speed remains nearly constant with load variations. The only change required in Fig. 9 to adapt it to represent this type of machine would be the addition of a motor field winding in series with the motor armature which would oppose the action of the shunt winding. Increase of armature current with increase of load would decrease the resulting field flux, thereby maintaining the speed constant. This would keep the frequency of the alternating current at a constant value, which is very desirable in radio work.

26. Alternators to be used in motor-generator sets may be of the revolving-armature type as well as of the revolving-field type. The operation and results are practically the same in either case. When the alternator is of the revolving-armature type, a field winding connected in series with the motor armature may be placed on the alternator so as to aid the field flux established by the winding that is in parallel with the motor armature. Decrease of speed with increased load is accompanied by an increase of current in the series winding. This in turn increases the field flux of the alternator and the alternator voltage is kept nearly constant.

A 500-CYCLE REVOLVING-ARMATURE ALTERNATOR CONNECTED TO A DIRECT-CURRENT MOTOR

27. A motor-generator set for furnishing 500-cycle alternating current from a direct-current supply is shown in Fig. 10. The frame *a*, view (*a*), of the machine is normally enclosed by screens over the ventilating openings to permit air circulation and prevent to a large extent the entrance of injurious substances. The rotor, view (*b*), is arranged with the motor armature *b* and the alternator armature *c* mounted very close together forming a compact unit. The motor-armature coils are connected to the commutator *d*, which, by means of brushes and leads, completes the path for current from the source of supply. The motor-field windings *e*, view (*a*), serve to energize the field circuit. The revolving-armature alternator has been described under that heading in *Generation of Electromotive Force*, Part 1.

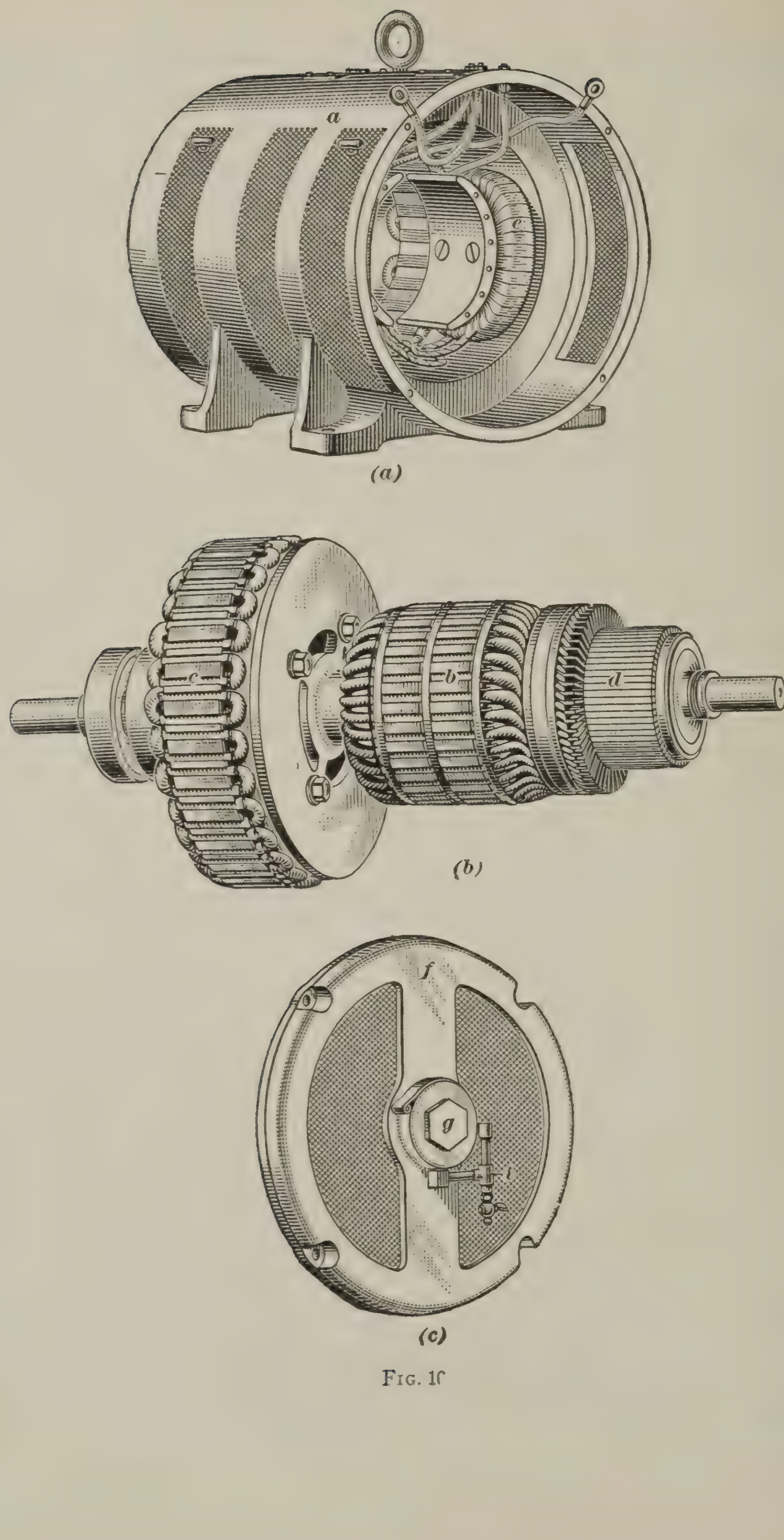


FIG. 10

There is an *end plate f*, view (*c*), at each end of the frame which carries bearings *g* for the rotor shaft. A small oil gauge *i* shows the height of oil available for lubrication of the bearings. Supports for the motor and alternator brushes are carried on the inside of the end plates at their proper ends. The end plates are also closed by means of screens. The units comprising a motor-generator set need not differ materially from those same machines when used individually.

A 500-CYCLE INDUCTOR ALTERNATOR OPERATED BY A DIRECT-CURRENT MOTOR

28. Fig. 11 shows a direct-current motor directly mounted on the same shaft with an inductor alternator. When oper-

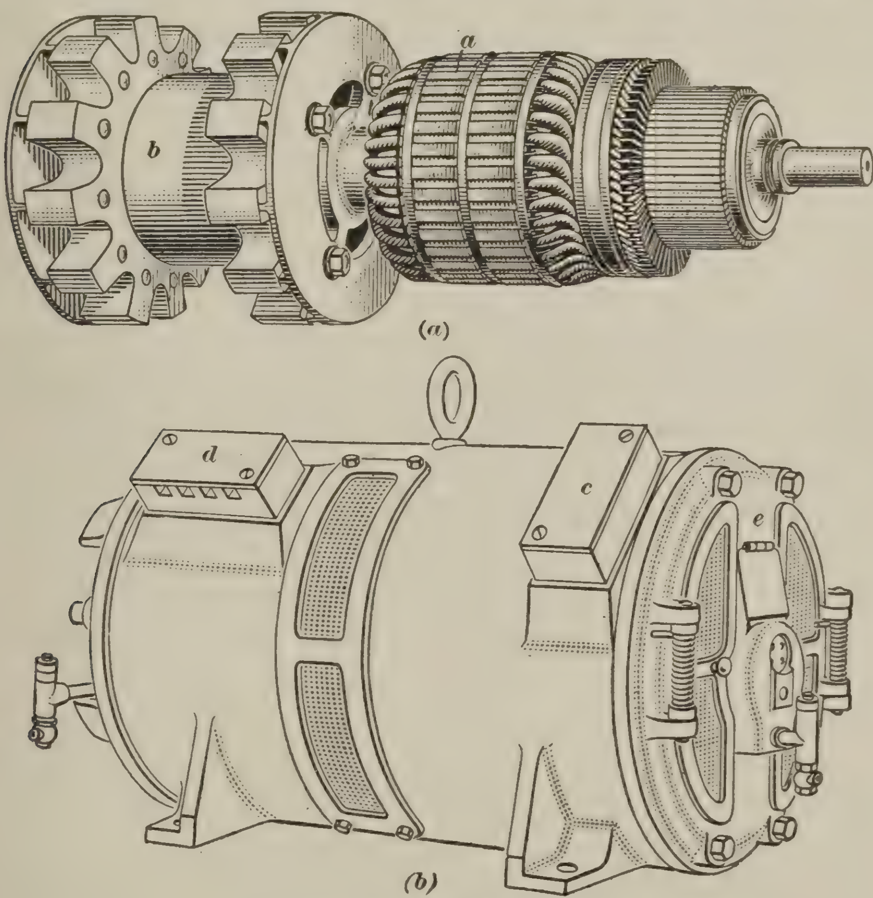


Fig. 11

ated at its proper speed, the alternator furnishes 500-cycle alternating current. The direct-current motor armature *a*,

view (*a*), with its field winding presents no marked variation from the usual construction. The characteristics of the inductor-alternator rotor *b* with its proper armature and field windings were stated in *Generation of Electromotive Force,* Part 1.

The assembled machine is shown in view (*b*) with exits for the direct-current leads at *c* and for the alternating-current leads at *d*. The end plate *e* at the direct-current motor end is shown properly mounted on, and fastened to, the frame. The brushes and brush holders are mounted on the inside of the end plate and the brushes bear on the commutator of the motor. The ventilating openings of this machine are protected by wire screens. The motor-generators illustrated in Figs. 10 and 11 are made by the Crocker-Wheeler Company.

ROTARY CONVERTERS

29. If circuit connections are made through slip rings and taps to opposite sides of the armature winding of a two-pole, direct-current generator and the machine is driven, an alternating current will be established in the circuit connected to the slip rings and a direct current may be taken from the commutator. In that case, the machine is called a *double-current generator.*

If direct current is supplied to the commutator, the machine will operate as a direct-current motor and an alternating current can be obtained in the circuit connected to the slip rings. The armature conductors in cutting the magnetic flux have alternating electromotive forces generated in them and an alternating current will pass through the slip rings and external circuit, since the current in that circuit is not rectified by a commutator.

When the machine is operated as an alternating-current motor by a supply of alternating current through the slip rings, direct current may be obtained from the commutator. When the machine is used to convert direct current to alternating current or alternating current to direct current it is called a *rotary converter,* or sometimes a *synchronous converter.*

There is only one armature and one field-coil circuit and with this arrangement one machine accomplishes what the

usual motor-generator set does with two machines. Any change of impressed voltage on the rotary converter changes the output voltage, which makes the machine objectionable for use in certain kinds of work. The output voltage drops to some extent when the machine is loaded because of increased losses in the windings. The drop of output voltage cannot be corrected without the use of auxiliary apparatus, as the armature winding is common to both circuits.

DYNAMOTORS

30. Some machines in rather infrequent use employ one magnetic circuit acting on an armature with double windings. They are known as *dynamotors,* and are used to change direct current from one voltage to another. The commutator of one armature winding is mounted on one end of the shaft and the commutator of the other winding is mounted on the opposite end of the shaft. The ratio between the voltages in the two circuits is constant except for the slight variation due to losses in the machine.

31. Motor-generators, rotary converters, or dynamotors may be used as double-current generators by driving the machines by means of steam engines or other prime movers. Circuits may be connected to the commutators or slip rings and direct currents taken from the commutators and alternating currents from the slip rings. Either one or both of the circuits connected to a machine may be active.

CONTROL DEVICES FOR DIRECT-CURRENT MOTORS

COUNTER ELECTROMOTIVE FORCE

32. When an armature conductor is forced by motor action to move across the flux of the field magnets, an electromotive force is generated in it. This electromotive force is usually called *counter electromotive force,* but it is also known as *motor electromotive force, back electromotive force,* and *back voltage.*

An armature has but a very low resistance—a fraction of an ohm in many cases—and if the armature is clamped so that it cannot rotate and the full voltage of the line is then impressed on its terminals, the windings would probably be damaged by the resulting large current.

If the armature is free to rotate, the counter electromotive force established in the active conductors acts in direct opposition to the impressed electromotive force from the power circuit, and thus limits the current. As the speed increases, the counter electromotive force increases and the armature finally reaches such a speed that the opposing action of the counter electromotive force is such that just enough current is taken by the motor to develop the required torque. In the case of a shunt motor, if the load changes, the speed varies slightly and there is automatically established a new value of the counter electromotive force that is suitable for the new value of the current required for the motor load.

The pressure that is actually effective in forcing current through the armature is the difference between the impressed electromotive force and the counter electromotive force. This difference is usually only a few volts, because the ohmic resistance of the armature is so low that only a low effective voltage is required to force the current through the windings.

PURPOSE OF STARTING RESISTANCE

33. In starting very small motors, the voltage of the line may be impressed directly on the armature terminals, because these armatures have a comparatively high ohmic resistance. In larger motors, the impressed voltage is adjusted to a lower value for starting by the insertion in the armature circuit of an adjustable resistance, called a **starting box, starting rheostat,** or **motor starter.** As the speed and counter electromotive force of the armature increases, the resistance of the rheostat is gradually cut out of circuit until, finally, the armature is connected directly across the line wires.

With smaller rheostats, the face plates, on which are mounted the arms and contacts by means of which resistance sections are cut into or out of circuit, are placed on the front of the box containing the resistance coils or grids. With larger rheostats, the face plates may be mounted on a switchboard and the resistance sections installed separately.

STARTING BOX OF SIMPLE TYPE

34. Fig. 12 shows one type of motor starter connected to a motor and its power circuit. This box has four terminals for connections to external circuits. A protective coil *a* is mounted on the face plate. This coil will hold switch lever *b* when the lever is at its on-position. The lever is shown in its off-position. The connection to the positive line is then open and the motor is at rest. To start the motor, switch *c* is closed, thus connecting the starter to the line, and the switch lever is moved to the right, making contact with button *d*. The shunt-field circuit of the motor is then energized. At the same time the armature circuit is closed through the resistor sections *e*. The current established will depend on the voltage and on the resistance active in the motor starter and of the rest of the armature circuit. Under normal conditions there will be sufficient current so that the armature will start to rotate and a counter electromotive force will then be established in the armature conductors. In case of a heavy load on

the motor, the lever may move over two or three contact buttons before the motor starts.

Further movement of the lever reduces the active resistance in the starter and the motor armature comes up to normal speed. At the extreme right-hand position of the lever, all of the resistor sections are cut out of the armature circuit and the armature is connected directly across the power circuit. This is the normal running position of the lever.

The holding coil *a* in series with a resistor *f* and the armature-starting resistors to the left of lever *b*, when the lever

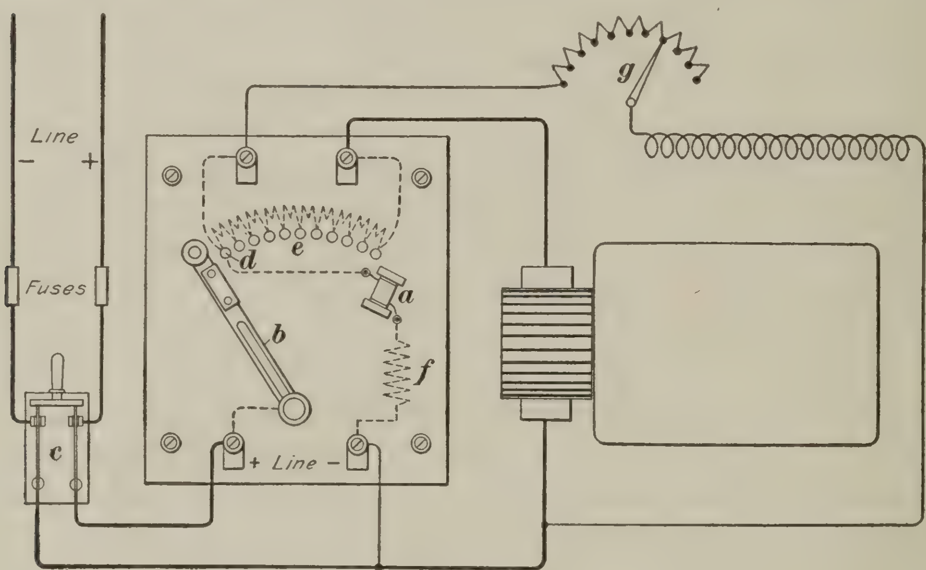


FIG. 12

is at its on-position, is connected across the circuit. The resistors *e* have a very low resistance as compared to the resistance of coil *a* and resistor *f*. The coil holds the lever in its on-position, but if the power circuit is opened, the magnet *a* releases the lever and a spring carries it back to off-position. The motor stops and must be started again when the line is in operating condition.

Speed control is accomplished by changing the active resistance of the field rheostat *g*. A change in the current in the field circuit changes the field flux and this affects the speed that is required to generate the proper value of the counter electromotive force for the given load conditions. It is important

when connecting up a starting box that all connections be made exactly as specified for proper starting and operation of the motor. The terminals on the box are usually designated by names or letters representing the correct circuit connections for each terminal.

STARTING BOX WITH OVERLOAD PROTECTION

35. *Overload protection* is also incorporated with starting devices by arranging a magnetic latch to release the switching device if the current in the armature becomes too great for safety. A release of this sort that operates by demagnetizing the low-voltage release magnet is not effective against overloads while starting a motor, since it affords protection only when the switching device is in the running position.

The starter shown in Fig. 13 has an overload release that is effective whenever the starting lever is over any of the resistor contacts.

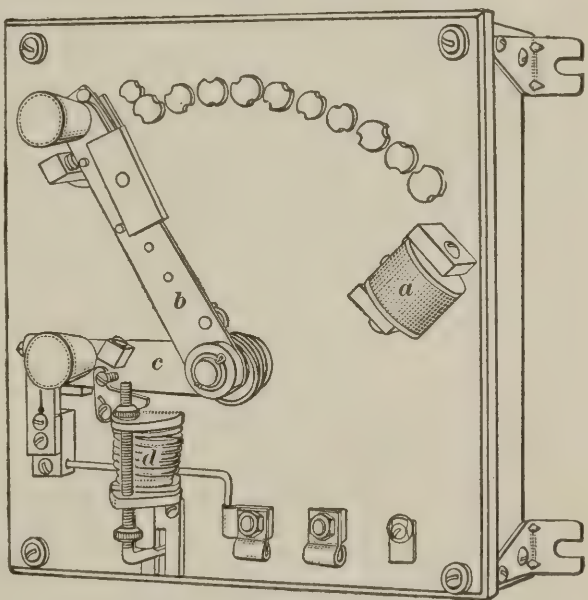


Fig. 13

The connections are shown in Fig. 14, in which the reference letters are the same as those in Fig. 13. The low-voltage release coil *a* is energized when the starting lever *b* rests over any of the resistor contacts *1*, *2*, *3*, etc., provided the overload release lever *c* remains in the position shown in both illustrations. If the current becomes too great for safety, the overload coil *d*, through which passes the total current taken by the motor, releases lever *c*, which is thrown open toward lever *b* by a spring, thus opening the motor circuit. Both levers must then be returned to the off-position at the extreme left before another start can be made.

The field connections shown by full lines are those of a shunt motor; the series field of a compound-wound motor would be connected as shown by the broken lines, the direct circuit connection between the series-field terminals *e* and *f* then being open.

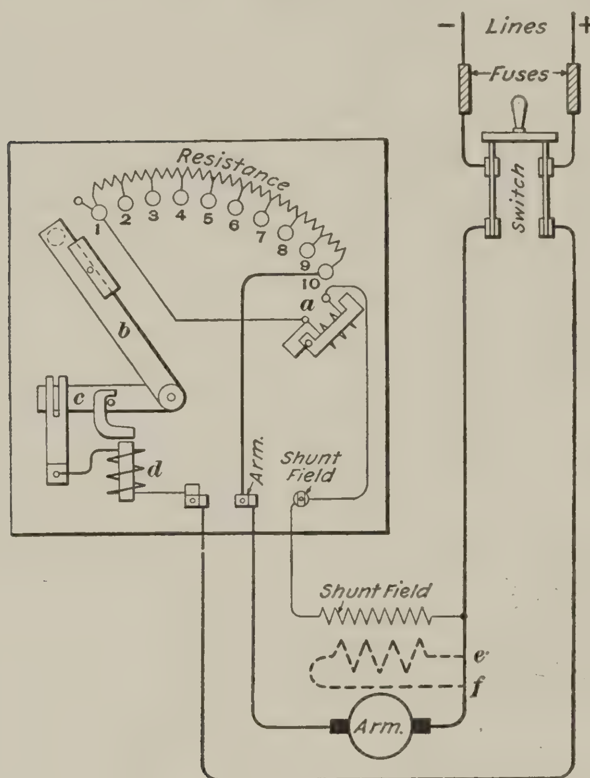


Fig. 14

36. A field rheostat for speed control could be connected in series with the shunt-field winding, Fig. 14. The starting box, Figs. 13 and 14, has but three terminals for external connections, but performs the same functions as the box shown in Fig. 12 and in addition has an overload release. There is a slightly different arrangement of circuit connections for the two boxes. Either the armature or field connections may be reversed more readily with the four-terminal type of box when it is desired to reverse the direction of rotation. This is not commonly required, however, in general electrical practice.

PROTECTIVE DEVICES

37. Fuses.—In addition to the protective devices mounted on the face plate of a starter, such as the low-voltage release coil *a*, Figs. 12, 13, and 14, and the overload coil *d*, Figs. 13 and 14, fuses and, in some cases, circuit-breakers are also installed in the motor circuit, usually near the main switch. **Fuses** are short pieces of metal that will melt at a compara-

tively low temperature. They are usually encased in a fiber tube and installed as shown in Figs. 12 and 14. The fuses will carry the normal current for the motor indefinitely, but will melt and open the circuit in case the current exceeds a safe value. A new fuse must then be installed.

38. Circuit-Breakers.—Where overloads are of frequent occurrence, a special type of switch, known as a *circuit-breaker,* is often installed, in some cases in addition to the main switch and in others in place of the main switch. The switch blade is closed against spring pressure and is held closed by a catch. A coil connected in series in the circuit connected to the breaker actuates a trip which releases the catch when the current exceeds a predetermined value. The switch blade opens the circuit very quickly, thereby affording the necessary protection for the motor. The main advantage of the circuit-breaker is that the switch blade may be easily closed, which will place the circuit in operating condition without the expense and delay occasioned by the renewal of fuses. The circuit-breaker can also be *tripped,* or opened, by hand, thus serving both for overload protection and as a line switch.

STARTING AND STOPPING A MOTOR

39. Starting a motor with starters like those shown in Figs. 12 and 13 is accomplished by first closing the line switch and then moving the starting lever over the row of resistance contacts, frequently called *steps,* or *points.* The movement should be slow enough to allow the motor speed to accelerate smoothly. On the point at the extreme right, the lever is held by the low-voltage retaining magnet; this is the point on which the lever remains while the motor is running and is therefore called the *running point.* The lever will not remain at rest on any intermediate point and must not be held there longer than necessary for the speed to pick up.

Stopping a motor with any of the starters illustrated is generally best accomplished by opening the line switch, or circuit-breaker. A circuit-opening device should be a part of every

motor installation. When the switch is opened, the motor speed and the counter electromotive force will decrease. The current in the low-voltage release magnet, now due to the counter electromotive force, will soon be so low that the magnet will release the rheostat switch lever which will then return to off-position.

MOTOR-SPEED REGULATION

40. Changes in the speed of a direct-current motor can be effected by changing the impressed voltage at the motor brushes or by changing the field strength of the motor. In either case, the motor speed automatically changes enough to keep the difference between the impressed volts and the counter volts at the value necessary for the torque. Speed-regulating devices for controlling the speed by varying the voltage impressed on the brushes are the same in appearance and in general design as motor-starting devices, the chief difference being that the contacts and resistors of regulating devices are generally larger, better to withstand the more severe service imposed on them. The resistors of motor starters are selected to carry a large current during only the short period required to accelerate the motor speed. In most cases these resistors would be overheated and possibly ruined if left in the circuit too long, that is, if too much time is taken to start, or if used to control the speed.

The more common and desirable method is to secure speed control by a field rheostat as indicated in Fig. 12. The field rheostat is usually placed near the operator so that he may have direct control of the speed of the motor.

SINGLE-STEP AUTOMATIC STARTER

41. The starting device may also be of the *automatic motor-starter* type, in which case the switching is done automatically, each operation cutting out a section of resistance when the motor speed has accelerated to the proper point.

The automatic starter shown in Fig. 15 is of the *single-step* type, as there is only one resistance step to be cut out of the

circuit when starting. The single-step starter is satisfactory when used with motors of rather low power output as they will readily reach full speed especially when starting without load. Closing the line switch *a* serves to establish a current through the motor armature *b* which is limited in value by the current-limiting resistance *c*. As the speed of the rotor increases, the counter electromotive force of the armature increases. The coil *d* is connected in shunt across the brushes and hence the voltage across the coil is the same as that across the motor. When there is sufficient current in the coil, plunger *e* is drawn up and the resistance *c* is short-circuited by the bar across con-

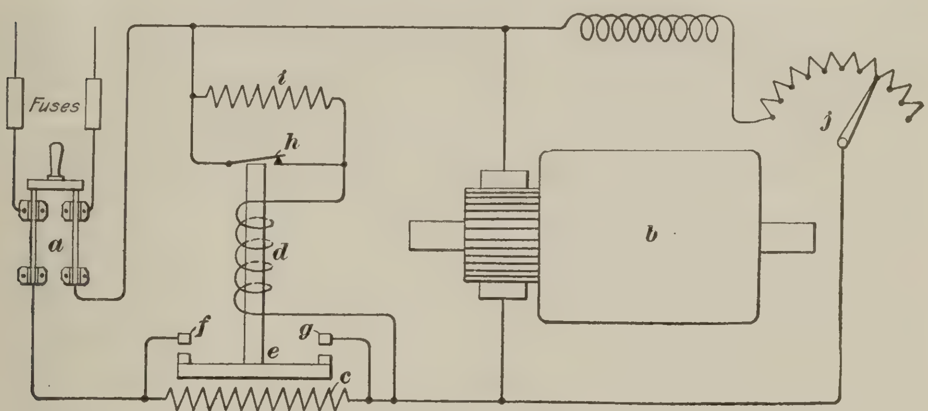


FIG. 15

tacts *f* and *g*, thereby placing full line voltage on the motor. Simultaneously with the rise of the plunger, the key *h* moves upward placing resistance *i* in series with coil *d*, which operation decreases the current through this branch circuit. The smaller current through the coil is sufficient to hold the plunger in position, and reduces the likelihood of the coil becoming overheated.

Speed adjustment of the motor is by variation of the field current through changes in the field rheostat *j*. Opening the line switch stops the motor and the plunger drops, due to gravity, to its proper position for the succeeding start.

THREE-STEP AUTOMATIC STARTER

42. A complete circuit diagram for a *three-step automatic motor starter* connected to a motor-generator set is shown in Fig. 16. The apparatus mounted in the box *a* is designated as the motor starter, while that at *b* is an overload relay serving as auxiliary protective apparatus. When the line switch *c* is closed as shown and the operator's control switch *d* is open, a circuit is completed from the positive line through the shunt-field rheostat *e*, shunt-field winding *f*, and overhead coil *g* of the overload relay, to the negative side of the direct-current supply line. The motor field *f* is now energized.

If the machine is to stand idle for some time the main-line switch should be opened, but it is normally left closed. The current in the shunt field is usually small and the power loss is not objectionable when operating intermittently in view of the better starting and stopping characteristics obtained.

To start the motor-generator set, the operator closes the control switch *d*. This operation closes a circuit starting with the positive line, through resistance *h* and coil *i* to the lower contact of the overload relay and its lever *j*, then through control switch *d*, and back to the negative line. The current through coil *i* draws up the plunger *k* which makes contact with point *l*, between which point and points *m*, *n*, and *o* are connected the resistance units of the three steps. The rotor will now start due to current through the circuit from the positive line to point *o*, through the resistance units, point *l*, plunger *k*, and flexible connection *p* to the positive armature connection, thence from the negative armature connection through coil *g*, to the negative side of the line. Further movement of plunger *k* cuts out the three resistance steps and the motor attains full speed. The rapidity of stepping up of the plunger is controlled by the adjusting point of the resistance *h*. When the movement of *k* is completed, the shunt around *h* is opened automatically making the holding current through coil *i* small. The motion of the plunger *k* is steadied by the action of a piston in a vacuum chamber and this action permits a slow regular advance. After the plunger brings the motor up to full speed on point *o*, it also

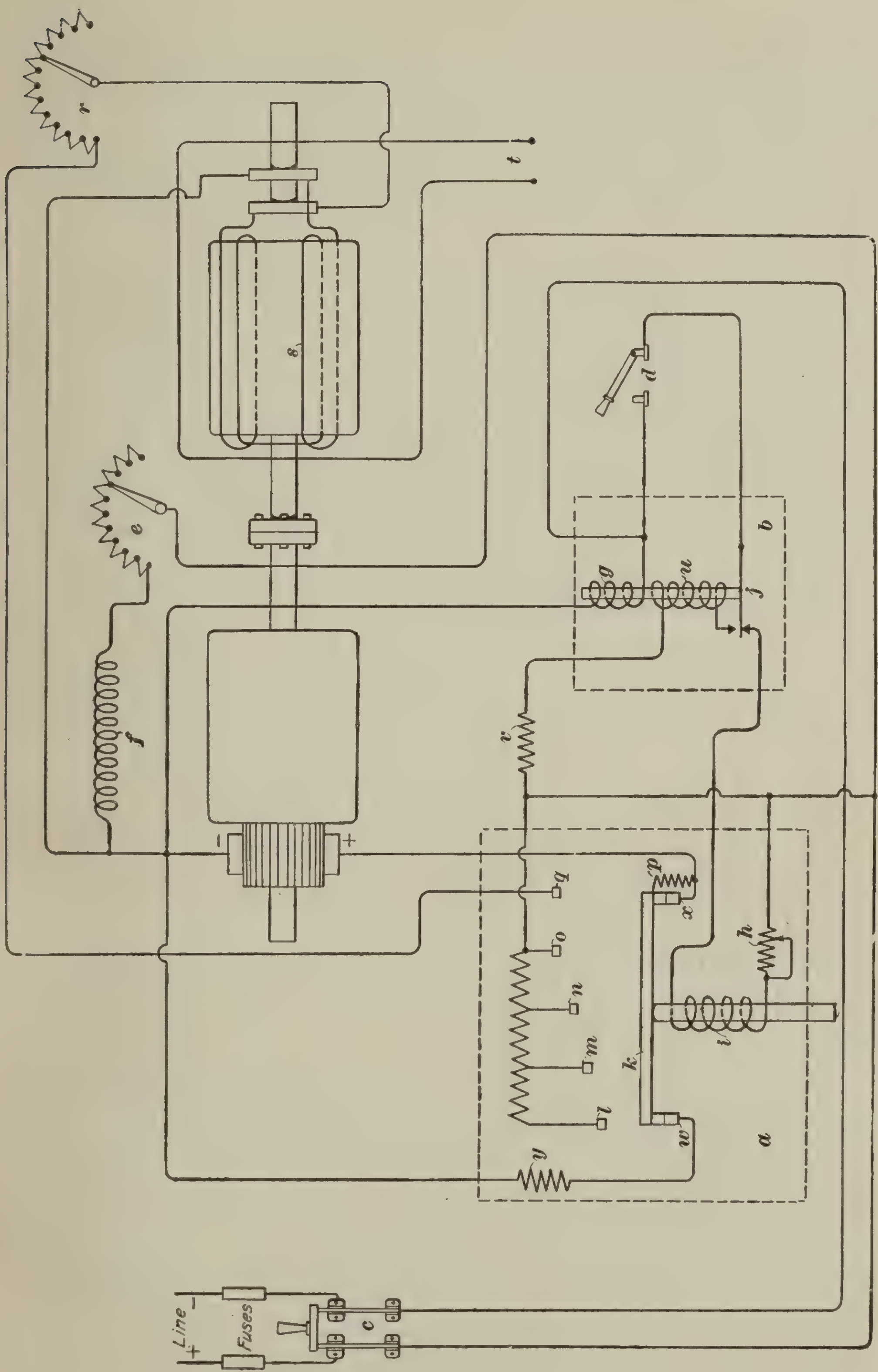


Fig. 16

makes contact with point *q*. A circuit is now established through the alternator field winding as follows: the positive line to point *o*, through plunger *k* to point *q*, thence through the alternator field rheostat *r* to the inner slip ring, through field windings *s* and outer slip ring to coil *g* and negative line.

43. Speed control of the motor, and consequently of the frequency of the alternator, is accomplished by varying the motor-field rheostat *e*. The alternator-field rheostat *r* serves to control the alternator voltage at the terminals *t* by changing the current in the field circuit of the alternator.

The weight of the plunger inside coils *g* and *u* of the overload relay normally keeps the lever of switch *j* down against the lower contact. The control circuit is then complete and is in its normal operating condition. Should the current through coil *g* become excessively large, due to overload or other unnatural condition, the iron plunger will be drawn up, by increased electromagnetic action, thus opening the lower switch contact of *j* and closing the upper contact of the same switch. Opening the lower contact of *j* opens the circuit through coil *i*. The plunger *k* then falls and opens the motor armature circuit. The closing of the upper contact of switch *j* energizes coil *u* in the circuit established through the positive line, resistance *v*, coil *u*, upper contact of switch *j*, control switch *d*, and to the negative side of the supply line. This serves to hold the lever *j* on its upper contact until control switch *d* or switch *c* is opened, thus preventing restarting until the trouble can be investigated and corrected.

When the control switch *d* is opened to stop the motor, the coil *i* is deenergized and plunger *k* opens the armature circuit in practically the same way as has just been described. In either case plunger *k* falls across contacts *w* and *x* and makes a low-resistance path between them. A circuit is now closed through the positive armature terminal, contact *x*, plunger *k*, contact *w*, resistance *y*, to the negative armature terminal. As the motor field is excited and the armature will continue to rotate due to inertia, an electromotive force will be generated, sending considerable current through the resistance *y*. This

will provide a dragging load on the motor armature and bring it to a quick stop, so that the operator may begin receiving very soon after he quits sending. The three-step starter is particularly desirable in starting large motors, and in giving an acceleration more uniform and steady than would be possible if fewer steps were used.

44. The current through the control switch *d*, Fig. 16, is only enough to excite the coils *i* and *u* and is so small that an ordinary snap switch or push-button switch can be used. The switch can be located at any convenient point near to or remote from the starter. For example, such a starter can be located near its motor and controlled by means of a small hand-operated switch some distance away. Closing the switch causes the relays to operate and start the motor; opening the switch causes the relays to open and stop the motor.

INDUCED ELECTROMOTIVE FORCE

PRINCIPLES OF INDUCTION

SELF-INDUCTION

45. Suppose that a helix or coil of wire is carrying a current supplied from some external source, as in Fig. 17. If the strength of the current is suddenly increased, a change in the number of lines of force occurs. This change induces in the conductor an electromotive force that opposes the original current in the coil and tends to keep the current from increasing in strength. The original current eventually reaches its maximum strength in the coil, as determined by Ohm's law, but its rise is not instantaneous; it is retarded to a certain extent by this induced electromotive force, which is called the *electromotive force of self-induction.* If, on the contrary, the strength of the original current is suddenly allowed to decrease, another change is produced in the lines of force that pass

through the coil; this new change induces in the coil an electromotive force that acts in the same direction as the original current and tends to keep the current from decreasing in value. The original current will eventually decrease to its minimum strength, as determined by Ohm's law, but it will decrease gradually and a fraction of a second will elapse before it becomes constant. In short, the current through a coiled conductor acts as if it possessed inertia; any sudden change in the strength of the current produces a corresponding electromotive force, which opposes that change and tends to keep the current at a constant strength.

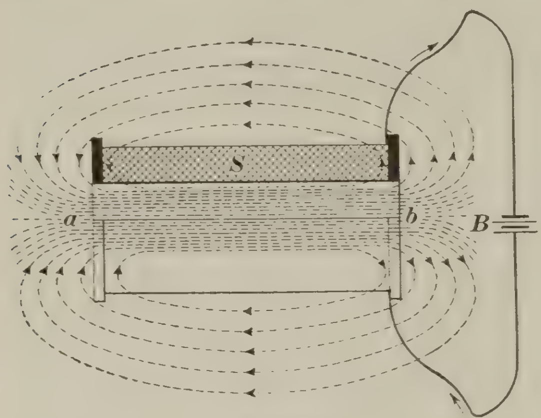


Fig. 17

SELF-INDUCTANCE

46. Self-inductance may be defined as the property of an electric circuit that tends to impede the introduction, variation, or extinction of an electric current through it. Therefore, a circuit possessing self-inductance resists any change, and especially a sudden change, in the current in the circuit. Furthermore, the effect of self-inductance is to make any change in the current strength occur slightly later than it would if the circuit possessed no self-inductance. A coil as well as a simple circuit in which the number of turns is one, possesses self-inductance, or *inductance,* as it is very often called.

MUTUAL INDUCTION

47. If two separate coiled conductors are placed near each other, so that the magnetic circuit produced by one, which carries a current of electricity, will be enclosed more or less by the other, as shown in Fig. 18, an electromotive force is induced

in one coil by the other, by **mutual induction.** The coil P in which current from the battery is established, is called the *primary*, or *exciting coil;* the other S is called the *secondary coil*. Any change in the strength of the current in the primary coil will produce a change in the number of lines of force in the magnetic circuit, and, consequently, an electromotive force will be induced in the secondary coil. If the current in the primary coil is increasing, the electromotive force induced in the secondary coil will establish a current in the direction opposite to the current in the primary coil. If the current in the primary coil is decreasing, the induced electromotive force in the secondary coil will establish a current in the same direction as the current in the primary coil.

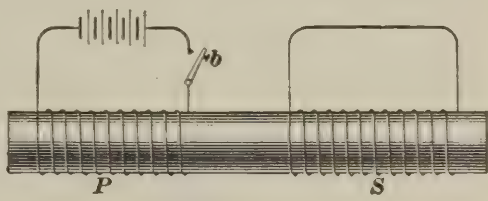


FIG. 18

INDUCTION COILS

OPERATION AND CHARACTERISTICS

48. An **induction coil** is an apparatus depending on the principle of mutual induction for producing a pulsating or alternating current of electricity. Induction coils consist essentially of two coils, primary and secondary, wound around a core consisting of a bundle of iron wires. In Fig. 19, the secondary coil S is composed of a large number of turns of fine insulated wire, while the primary coil P contains only a few turns of heavy insulated wire. Both coils are wound on a spool O of insulating material fitting over the iron core C.

The primary circuit is automatically opened and closed at D in the following manner: A spring F tends to keep the circuit closed between a platinum contact piece D attached to the spring F and the contact screw K. As soon, however, as the circuit is closed by the action of the spring, the current from the battery B begins to circulate through the primary coil P

around the core *C*, thereby magnetizing the core and causing it to attract the iron armature *H*, thus breaking the primary circuit between *D* and the point of the adjustable screw *K*. On opening the circuit between *D* and *K*, the magnetism in the core begins to weaken, the spring once more closes the circuit, and the entire operation is again repeated. These actions take place in rapid succession, a large number of times a second, constantly producing a change in the number of lines of force passing through the core, and thereby inducing a current in

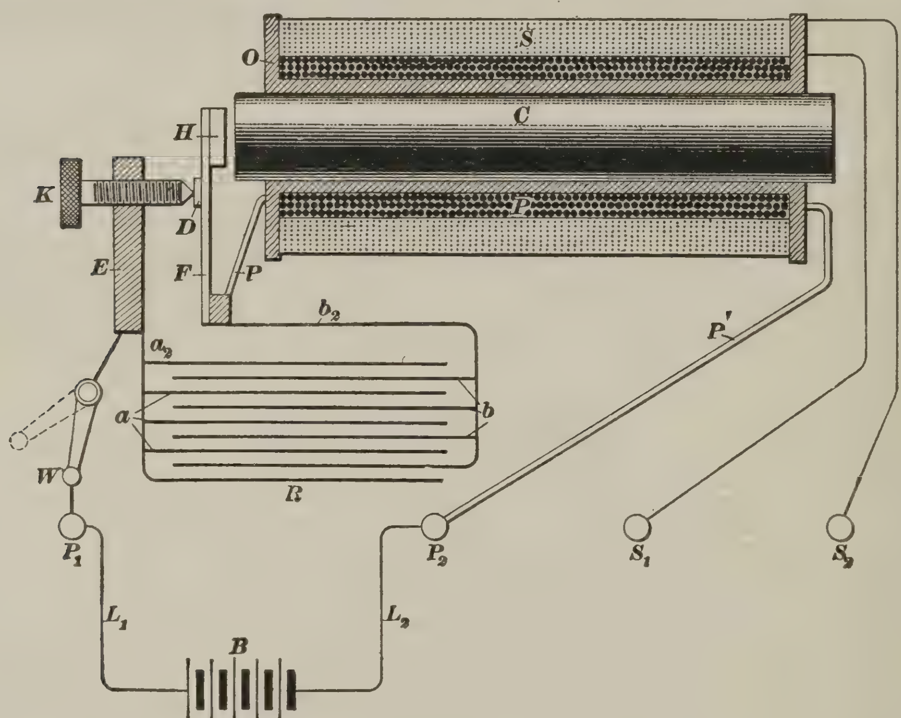


FIG. 19

the secondary coil. A switch *W* connects the post *E* with the terminal P_1, and the terminals P_1 and P_2 are joined to the battery *B* through leads L_1 and L_2. The terminals S_1 *and* S_2 of the secondary coil are not, for the present, connected with each other; the secondary coil is therefore open.

49. A condenser *R*, consisting of two sets of plates *a* and *b*, is connected across the break in the primary circuit and allows the magnetism of the core to decrease much more rapidly when the circuit is broken than if the condenser were not used. When the primary circuit is opened, its self-inductance tends

to keep the current passing across the break in the form of a spark; but when a condenser is used, this current passes and charges the condenser instead of producing a spark across the break. After the current has charged the condenser, the latter immediately discharges through the circuit a_2–E–W–P_1–B–P_2–wire P'–primary coil P–wire P–b_2 and back to the condenser R. This current, being in the direction opposite to the current due to the battery B, demagnetizes the iron core with great rapidity and thus produces an extremely high electromotive force in the secondary coil. At first, the electromotive force of self-induction establishes the current that charges the condenser. When the condenser discharges, the voltage of discharge is sufficiently high to overcome the opposing electromotive force of the battery and to force a small instantaneous current through the battery and the primary coil against the resistance of these devices.

The spark at D is very much less with this condenser than it would be without it. By trial a condenser of proper capacity may be selected so that it is possible practically to interrupt the current and reduce the magnetism of the core to zero almost instantaneously. In this way the maximum induction is produced in the secondary coil with a given current in the primary coil.

50. When electricity starts to flow in the primary circuit, the self-inductance of the coil compels a rather gradual increase in the current strength in the primary circuit, and, consequently, the induced electromotive force in the secondary coil is comparatively small. When the current in the primary is broken, however, the current not only almost instantly decreases from its maximum value to zero, but it is quickly followed by the reverse current from the condenser; consequently, a very intense electromotive force is produced in the secondary winding. Therefore, the tendency is to induce a very much greater current in the secondary winding in one direction than in the other. In most induction coils, a spark gap in the circuit of the secondary winding gives this winding a very high resistance; for this reason, the electromotive force

induced in the secondary coil, when the primary circuit is made, may be too weak to produce a spark, that is, a current, across the air gap. Hence, there may be no current in the secondary winding when the current in the primary is made. However, when the current in the primary is broken, the electromotive force induced in the secondary is usually sufficient to force a current across the air gap. As a result, a current may be produced practically in one direction only in the secondary winding. There is, of course, always a tendency to produce a current in both directions and doubtless there is a current in both directions in many cases.

51. The more turns that the secondary coil contains, the more will it be exposed to the effects of the inductive influences of the primary coil. The electromotive force developed in the secondary coil would, up to a certain limit, increase in direct proportion to the increased number of turns that is wound in the same space on the bobbin; but as the total power in watts developed in the secondary coil cannot be increased without increasing the power supplied to the primary, an increase in voltage can be obtained, with constant output, only at the expense of a decrease in current strength. Increasing the sectional area and decreasing the length of the wire in the secondary coil will decrease its voltage and increase its amperage for a given output.

52. Comparisons Between Various Coils.—When coils are mentioned it is customary simply to state their sparking distance, say 8, 10, 12 inches, or whatever the same may be. This gives no idea whatever of the real power of the coil. It is necessary to know not only the pressure indicated by the sparking distance, but also the strength of the current and the number of sparks produced per second. Two coils may be made to give exactly the same length of spark, but the sparks may be of a very different nature. In one case it may be thick and intensely white, and in the other thin and bluish. The former coil is the more powerful and the more expensive to build. To send this increased current through the secondary winding, the primary and secondary coils must both be made

of heavier wire, thereby increasing the expense for copper and labor.

53. A straight iron core is always used in induction coils, for when the current in the primary is broken, the magnetic flux falls from its maximum value, not to zero, but to a value known as the *residual magnetism*. This value in an open magnetic circuit is much less than in a closed magnetic circuit, so when the primary current is suddenly reduced to zero, the magnetism drops lower in an open magnetic circuit than in a closed one. As the electromotive force in the secondary is proportional to the reduction in the magnetic flux, it is greater with a straight core than with a complete circuit of iron.

For the iron core, properly annealed No. 24 B. & S. gauge iron wire is the most suitable, though No. 18 and No. 20 give satisfactory results and are used oftener. If one end of the core is used to operate the circuit-breaking device, it is filed smooth, but the other end may be left rough.

TYPES OF INTERRUPTERS

54. The *mechanical interrupter* shown in Fig. 19 is fairly satisfactory for low-power coils. It is not readily adjustable to different frequencies as the vibrating hammer H has a natural vibration frequency, and also possesses considerable inertia. If the current through the primary is very large or the primary voltage is high, it is good practice to interrupt the primary circuit at point D in oil. This procedure assists the condenser in preventing the formation of an arc when the circuit is periodically opened.

55. *Mercury interrupters* are made which depend upon the breaking up of a stream of mercury to interrupt the primary circuit. A motor is frequently used to operate the paddle-wheel arrangement whereby interruptions in the mercury stream are produced. This type of interrupter has given good results in many cases, but has not come into general use.

56. *Electrolytic interrupters* depend for their operation upon electrolytic action. The anode, which is in the primary

circuit, consists of a short length of fine platinum wire projecting from a porcelain tube into the electrolyte of dilute sulphuric acid. The cathode is usually a lead plate immersed in the electrolyte. When the current reaches a certain value, the resistance at the anode is increased by the formation of gas between the platinum wire and electrolyte. The circuit is practically opened by the gas formation, which now disappears because of the interruption of the circuit. The circuit is then reestablished and the cycle is repeated. Adjustment of the frequency is accomplished by varying the length of the platinum wire exposed to the electrolyte. Because of the characteristics of the current interruptions, there is no sparking and no condensers are necessary. With the electrolytic interrupter, it is possible to obtain much higher frequencies than with the mechanical type, for the reason that there are no moving parts.

TRANSFORMERS

GENERAL PRINCIPLES

57. A **transformer** is a device used on alternating-current circuits to change high-voltage energy into low-voltage energy, or vice versa. Such a device consisting of two coils *a* and *b* wound on an iron core is represented diagrammatically in Fig. 20. The action of the transformer is based on the fact that if the current varies in either one of the two coils, an electromotive force is induced in the other coil. If a source of alternating electromotive force is substituted for the battery and switch, Fig. 18, alternating current will be set up in the primary coil and an alternating

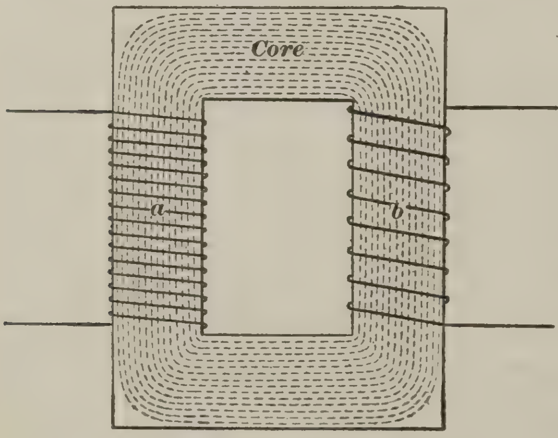


FIG. 20

flux in the core; in the secondary coil an alternating electromotive force will be generated by mutual induction and this force will establish an alternating current in the secondary circuit.

The coil supplied with current is called the *primary*, and the other coil in which the voltage is induced, due to the variation of the current in the primary, is called the *secondary*. Either of the two coils may be made the primary or the secondary, depending on which is connected to the source. The coils and core of a transformer are usually enclosed in an iron case.

58. Further, voltages applied and induced bear the same relation to each other as the number of turns of the primary bears to the number of turns of the secondary. For example, if the secondary has one-third as many turns as the primary, the induced voltage will be one-third of the applied voltage; if the secondary has three times as many turns as the primary, the induced voltage will be three times the applied voltage.

With current in the secondary coil, a current must also exist in the primary coil; and the two currents are always of such values that the product of the secondary current and the secondary voltage is approximately equal to the product of the primary current and the primary voltage. These conditions would exist in an ideal transformer, that is, one having no losses; but all commercial transformers have some losses due to resistance, iron-core loss, etc. that modify to some extent the ideal conditions.

GENERAL TYPES

59. The essential parts of a transformer, as represented by Fig. 20, are a rectangular iron core forming a magnetic circuit, and two coiled conductors *a* and *b* interlinked by the magnetic circuit. When one of the coils, for example *a*, is connected with a source of alternating voltage, this coil becomes the primary and receives energy, at some particular voltage, from the source. By means of the action of the alternating magnetic flux, indicated by dotted lines in Fig. 20, the voltage of the primary coil *a* is transformed into another voltage

which is made available at the terminals of the secondary winding b. In the usual type of transformer the primary and secondary coils are insulated from each other and are not connected electrically while in the autotransformer, described later, the primary and secondary coils are formed from parts of a single winding.

60. The **core-type transformer** consists of a single magnetic circuit of square, rectangular, or cruciform cross-section, with a rectangular opening, or *window*, to accommo-

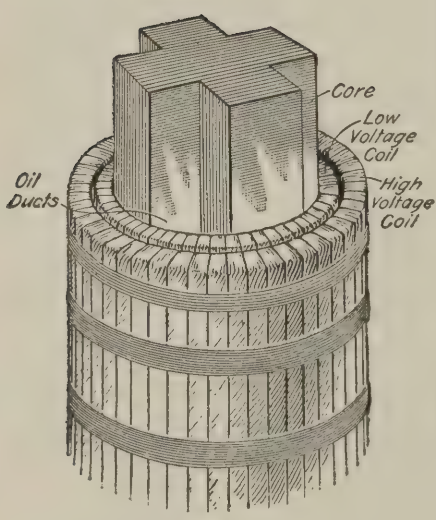


FIG. 21

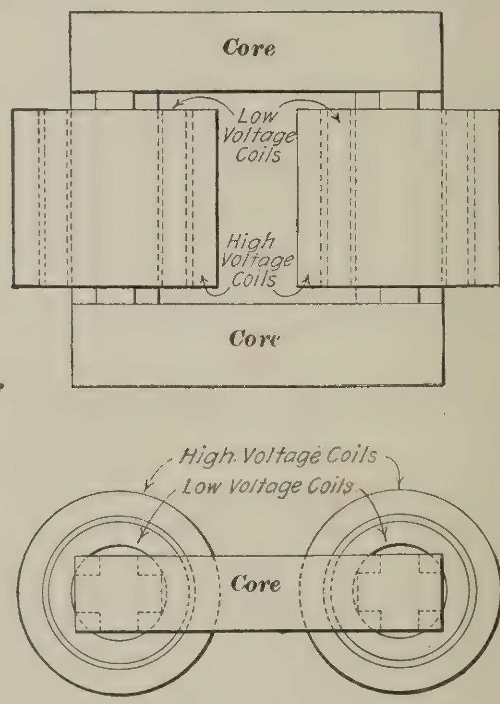


FIG. 22

date the windings. Fig. 21 shows one leg of a transformer of which the core has a cruciform cross-section.

The windings, which are usually of cylindrical shape, are placed on the two legs of the magnetic circuit, entirely surrounding them. Relative positions of the windings and core are shown in Fig. 22. The low-voltage coils, unless large and heavy connections prevent, are usually placed next to the core, and the high-voltage coils are external and concentric with them.

61. The **shell-type transformer,** Fig. 23, is distinguished by a divided magnetic circuit, all coils being on one leg. The middle leg is usually divided, as shown, virtually making two core-type magnetic circuits in multiple.

The windings on the shell-type transformer are usually of so-called *pancake* construction, shown in Fig. 23, the groups of high- and low-voltage coils being so arranged as to give the best operating characteristics.

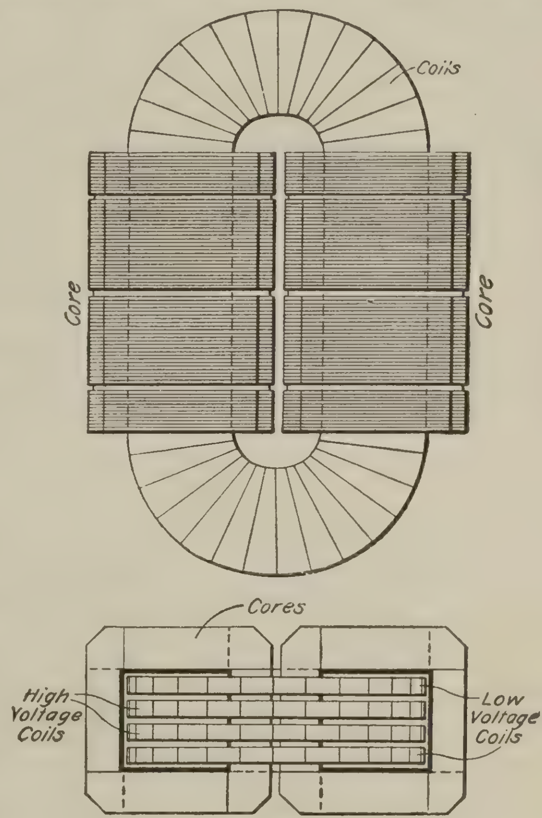


FIG. 23

COOLING

62. As in other electrical apparatus, heat is developed when there is current in one or both of the windings of the transformer. The losses causing this heating are brought about chiefly by losses due to resistance in the windings and to the rapid reversals of magnetic flux in the iron core. When the transformer is operating under rated load, the losses may be considerable and in large units special means must be provided for preventing overheating of the coil windings. The maximum capacity of a transformer is the maximum load it can carry without developing heat enough to injure the insulating material. This capacity can, therefore, be increased by employing means to cool the transformer. Among the common methods of cooling are *self-cooling, air-blast cooling,* and *oil cooling.*

Self-cooled transformers are those of small capacity and dimensions in which the ratio of the exposed surface of the active materials to the volume of the materials is so large that

no special means of cooling are considered necessary. The cooling is effected by natural air-currents created by the difference in temperature of the windings and the surrounding air, and by direct radiation. In the air-blast cooled transformer, which is usually of the shell type, the heat is carried away by air-currents forced through ducts in the windings and core. Oil-cooled transformers, especially in the larger sizes, are extensively used. The cores and coils of such devices are submerged in oil, which transfers heat from the windings to the outer tank. In addition to carrying away heat, the oil serves as an insulator between the various windings, and between the windings and the core.

RADIO TRANSFORMER

63. A transformer used in small-power radio installations is shown in Fig. 24. A simplified diagram of the same transformer is given in Fig. 25, and the same reference letters are used in both figures. The primary winding *a*, secondary coil *b*, and the common magnetic circuit *c* comprise the usual transformer elements. Suitable primary terminals *d* and secondary terminals *e* afford connections to the power supply circuit and output lines.

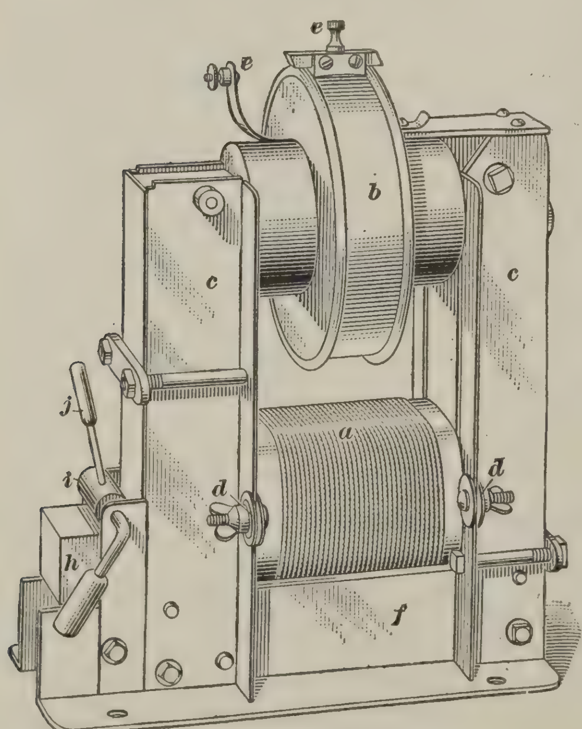


Fig. 24

64. In many cases it is desirable to change the power output of the transformer. This is readily accomplished by providing a magnetic shunt as shown at the left side of Fig. 25.

The shunt path for the flux is through the iron core *f* and the air gap *g*. This air gap may be completely closed by the tongue or armature *h*, its position being controlled by the small gear wheel *i* to which the handle *j* is fastened. The gear wheel *i* meshes with teeth on the tongue *h* and thus when rotated moves the tongue into or out of the air gap. When the tongue fills the air gap, there is a closed magnetic circuit through iron in shunt with the one through coil *b*. As there is considerable opposition to the establishing of flux through coil *b* when it is loaded, most of the flux will follow the path through core *f*. Withdrawing the tongue a short distance places an air gap in the flux path through *f*. The air gap offers greater opposition to the establishment of the flux than does the path formed entirely of iron, therefore some of the flux will shift from path *f* to path *c*. Continued withdrawal of the tongue increases the length of the air gap until it reaches such a value that practically all of the flux follows path *c*. The output is then a maximum and nearly all the flux which is produced is utilized in useful output. Other means may be used for changing the length of the air gap, but the principle is the same in any type. In any transformer employing the variable magnetic shunt, the input current will also decrease with decrease of output.

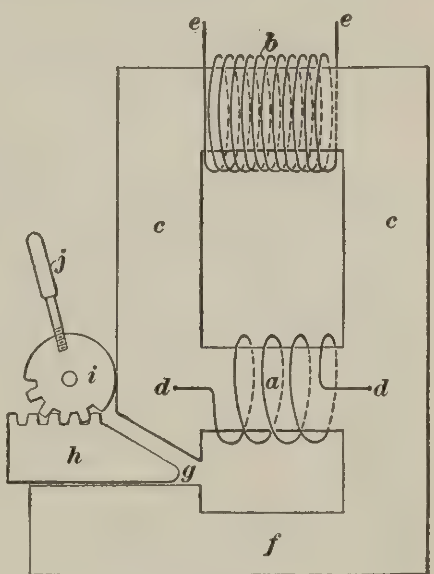


FIG. 25

AUTOTRANSFORMER

65. An **autotransformer** is a transformer having but one winding, which serves both for the primary and secondary coils. Fig. 26 shows the general arrangement; *A* represents the laminated iron core on which are wound two coils *t*, *t′* connected in series so that they practically form one coil. The primary line wires are connected to the terminals *a*, *b* and the

secondary line wires to *c*, *a*. The ratio of the secondary potential E_s to the primary potential E_p depends on the ratio of the number of turns t' to the total number of turns between *a* and *b*. For example, if t' is one-third the total number of turns, the voltage E_s will be about one-third the line-voltage and the current taken from the secondary will be about three times that drawn from the line wires. The secondary terminals may be connected to points anywhere along the coil.

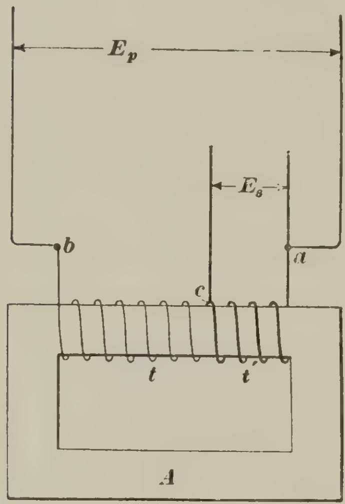


FIG. 26

The chief advantage of the autotransformer lies in the saving effected by the combination of the primary and secondary windings. The electrical connection between the high- and low-voltage coils is very undesirable in practice, on account of the liability of getting a high voltage impressed on the low-voltage windings because of faults in the windings or in the external circuits.

RECTIFIERS

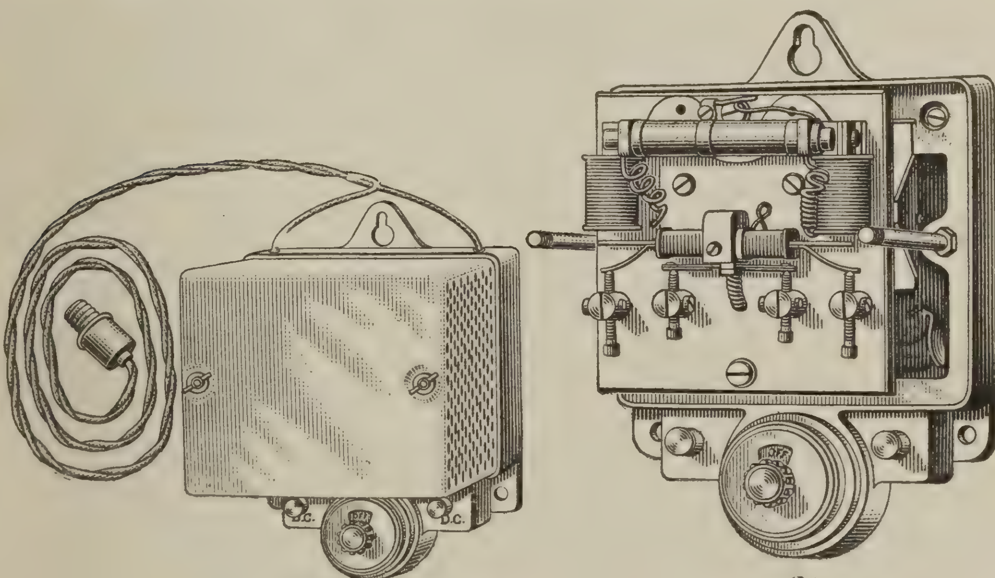
USES OF RECTIFIERS

66. Alternating current, on account of being so economically transmitted, is more commonly employed for lighting and industrial motor operation than direct current. Direct current is essential for charging storage batteries and for other applications. Where alternating current is the source of supply, means of changing from one kind of current to the other are required. This process is called *rectifying* the alternating current. Motor-generator sets are in common use where large amounts of energy are to be changed from alternating current to direct current. As their efficiency is rather low in the smaller sizes, other types of rectifiers have come into use for the rectifying of small amounts of energy.

MECHANICAL RECTIFIERS

67. Mechanical, or **vibrating, rectifiers** are being successfully used for charging storage batteries in many lines of work. These rectifiers consist essentially of switches that open and close automatically and at the proper time to give a pulsating direct current from an alternating-current supply. They operate in such a way as to intercept or rectify current half waves that are in one direction only, changing them so as to be in the same direction as the unchanged half wave.

68. Fig. 27 shows the appearance of one such vibrating rectifier; (*a*) is the complete device and (*b*) the same with



(a) (b)

Fig. 27

the cover removed. Fig. 28 shows the connections of the device. The secondary *3–5* of a small transformer is connected through regulating resistances *b* and *c* to two stationary platinum-tipped contacts *a′* and *a*. Above these two contacts are two platinum-tipped vibrating contacts carried by the pivoted core of a direct-current magnet. This core serves as the armature of two alternating-current magnets connected in series across one-half of the transformer secondary. The alternating-current magnets are so connected that both poles

which project downward have the same magnetic polarity at any given instant. The vibrating armature is polarized by a direct-current winding connected with the battery being charged, one end of the armature always being a north pole and the other a south pole. Each end is, therefore, alternately attracted and repelled by the poles of the alternating-current magnet above, thus keeping the armature vibrating at the proper speed with relation to the frequency of the alternating current, and making contact, first on one side and then on the other, with the fixed platinum points.

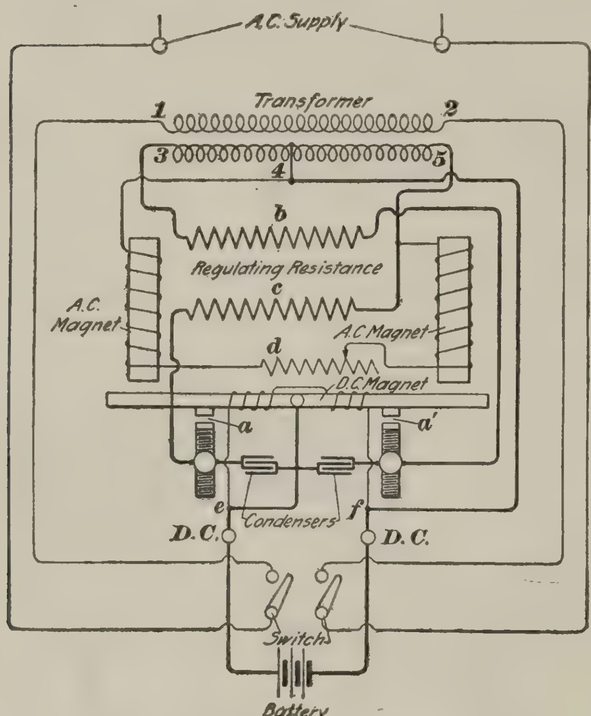


Fig. 28

The closing of these contacts is so timed as to rectify each negative half-wave, giving a *pulsating direct voltage and current*, as represented in Fig. 29. Here, line *a–b* represents zero voltage and line *c–d* the battery voltage. Only the rectified voltage above the battery voltage is effective in

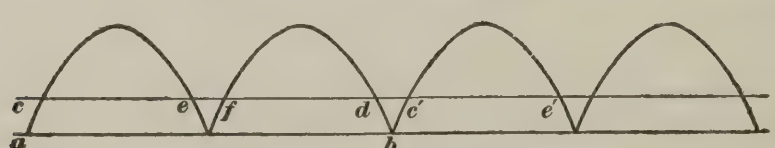


Fig. 29

charging the storage battery; that is, only the portion represented by the curves above line *c–d* is useful in charging the storage battery. The contacts are, therefore, timed to be closed at instants corresponding to points *c* and *f*, and to break at instants corresponding to points *e* and *d*. If either pair of

contacts were closed at points below the battery voltage, the battery would discharge through the rectifier. The period of time represented by the space *e f* lapses between the instant contact is broken on one side and made on the other by the vibrating armature.

By this means both alternating-current impulses or both half-waves are utilized. One passes from point *3*, Fig. 28, through the path *b*–*a′*–armature and pivot–*e*, where the current divides, part passing through the battery and part through the direct-current magnet to the point *f*, where the two parts unite and pass to point *4* of the transformer. The other impulse, starting from point *5*, passes through the path *c*–*a*–armature and pivot–*e*, from which the return to point *4* is the same as before. The current from point *e* is thus continuously in one direction through the battery and the direct-current magnet.

If the contacts *a* and *a′* are closed and opened at the exact instants of zero current, no sparking occurs. The resistor *d* serves to adjust the operation of the contacts and the condensers to remove slight tendencies to spark, so that the contacts remain uninjured for long periods. Springs keep the contacts open when the rectifier is not in operation, in this way preventing battery discharge through these contacts. This rectifier delivers current to the battery in the right direction regardless of the connections to the battery, because the battery polarizes the armature. No attention need be paid to polarity when making these connections, because both half-waves are utilized. If the supply circuit is interrupted temporarily, the rectifier restarts automatically as soon as the current is restored.

THE TUNGAR RECTIFIER

69. A bulb filled with an inert gas, called *argon*, and containing a hot and a cold electrode, may be used as a rectifier for changing alternating current to direct current. Fig. 30 shows a simple type of **tungar rectifier,** with upper cover removed. This device consists of a rectifier bulb *a*;

a compensator b; a fuse and receptacle c; alternating-current leads d; and direct-current leads e. The bulb is shown

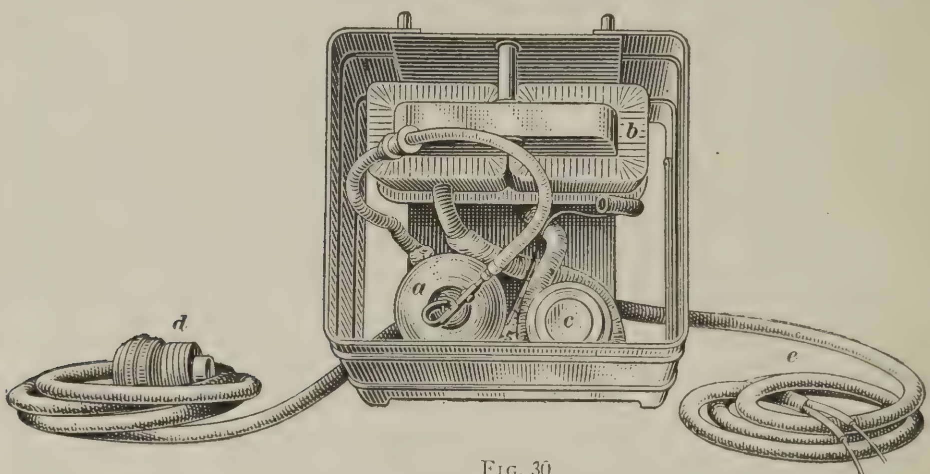


Fig. 30

separately in Fig. 31. The cathode a is a tungsten filament which is heated by alternating current taken from the compensator. The anode b consists of a piece of graphite.

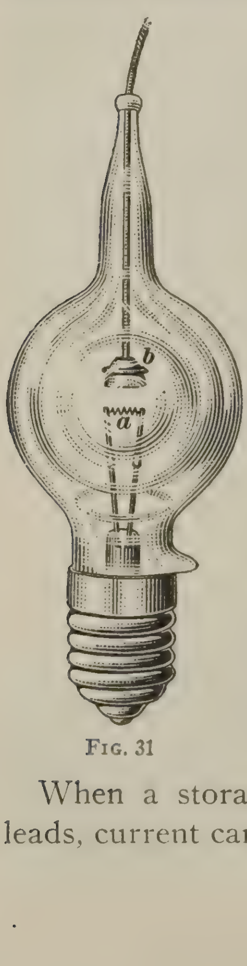


Fig. 31

The connections of the rectifier are indicated in Fig. 32. When the plug is connected to an alternating-current circuit, usually of 115 volts, the compensator winding is excited and a low electromotive force is applied to the filament. The effect of the heated filament on the gas is to make the gas conductive for a flow of electricity from the anode to the cathode when the filament is negative as compared to the graphite electrode. On the other half-wave of the cycle when the filament is positive as compared with the graphite electrode, the gas is non-conductive and current cannot pass between the two electrodes, therefore electricity can flow in only one direction through the bulb, from the anode to the cathode.

When a storage battery is connected to the direct-current leads, current can pass from what is at a given instant the posi-

tive lead of the alternating-current circuit, through the storage battery, the anode, the conducting gas in the bulb, the cathode and to some point on the compensator winding which at that instant is negative as compared to the positive lead that is directly connected to the battery.

At the instant when the red lead, Fig. 32, is connected to the negative side of the alternating-current circuit, current cannot pass through the bulb. In the particular device shown only alternate half-waves of alternating-current cycle are utilized. The battery cannot discharge through the rectifier bulb when the alternating-current circuit is open, because the gas is not conductive when the filament is cold.

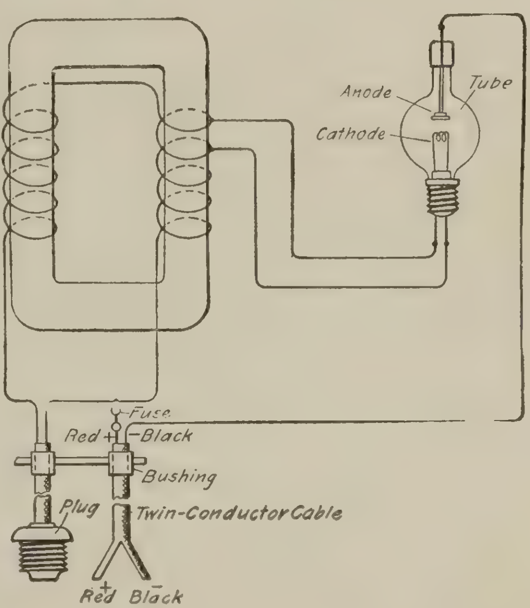


Fig. 32

To use the rectifier, the alternating-current leads are connected to an alternating-current circuit of suitable voltage and the other leads to the storage battery. This type of rectifier is made in several sizes to charge storage batteries of different current capacities and voltages. In some types, voltage adjustments covering a considerable range can be made through taps to the compensator. Care should be taken that the voltage of the battery to be charged is less than the voltage that can be delivered to the direct-current leads by the action of the rectifier.

CODES AND CODE PRACTICE

INTRODUCTION

DEFINITION OF TELEGRAPHY AND TELEPHONY

1. **Electric telegraphy and telephony** are branches of the art, science, or process of transmitting intelligible signals or information between distant points by means of electric impulses moving between those points. Messages may be transmitted in this manner to produce audible signals. The essential parts of these systems are the transmitting and receiving devices, and the mediums which carry the electric impulses.

2. In the common **wire telegraph** and **telephone** systems the impulses are carried from one party to the other by means of wires, or at least, one wire and ground return. There is thus a complete electric circuit between the two stations, which circuit is a part of the necessary apparatus in this method of communication.

3. In **radio** practice, no wires are used between the distant stations, the signals being carried by a medium called *ether* which is supposed to fill all space and which allows of the transmission of waves of energy. Special apparatus produces and sends out electric impulses which are readily carried by the ether. These impulses, by means of special receiving devices, are made to produce audible signals, by means of which the electric impulses become intelligible. As no wires are used between the communicating stations, this system is sometimes

called *wireless*. The name wireless, however, may be applied to other systems of transmitting signals not employing electricity, as, for example, one using beams of light that are interrupted at intervals so as to produce long and short flashes.

4. In both wire and radio telephony, special sets of signals are not necessary and consequently not used. Communication on these systems is by word of mouth and the messages are received by the human ear. Communication by telephony is, therefore, much more rapid and convenient than by radio telegraphy and accounts for the rapid development of this branch of the radio art.

CODES

MORSE CODE

5. Telegraph codes consist of *characters* formed by combinations of dots, dashes, and spaces, which represent letters, numerals, and punctuation marks. These characters are sent by one operator to the other by means of electric impulses. With the aid of suitable apparatus, the receiving operator hears the incoming signals and is then able to reproduce the original message. The characters representing letters, figures, and punctuation marks for the International Morse code, the Morse code, and the Phillips punctuation code, which is used as a part of the Morse code, are to be found in the latter portion of this Section under the heading Operating Hints.

6. The **Morse code** of characters came into general use in wire telegraphy shortly after the establishment of that means of communication. In this system, which is also called the *American Morse code*, some of the characters are made with so-called *spaces* which are a part of the group signal, and are essential in distinguishing those characters. The use of spaced letters in this system quite frequently leads to errors in the transmission of messages, as the parts of those letters are apt to be divided into two letters, or two letters composed of a small

number of signals may be combined unintentionally to form a single letter. This does not imply that no mistakes are made when other codes are used, but rather that they are apt to be more common in the Morse for the reason given. It is usually somewhat more difficult to learn a code with spaced letters than one which does not have any spaces as part of the letter characters. The *Phillips punctuation code* has superseded the punctuation characters of the Morse code as it is much more complete and systematic.

INTERNATIONAL MORSE CODE

7. The **International Morse code** is a modified form of the Morse code in which no spaced characters are used, except in the character for the period. This alphabet is also commonly called the *Continental*, and the *Universal code*, and has come into extensive use in some fields.

The International Morse code is used all over the world for radio and submarine telegraphy, and for wire telegraphy in almost every country except the United States, Canada, and parts of Australia. It is superior for signaling through long submarine cables, as some of the recording devices used in that work do not give accurate signals when used with spaced letters.

The Morse code, owing to the fact that there are fewer dashes in its characters, is about 5 per cent. more rapid than the International Morse code. The latter is, however, preferable for several reasons and would doubtless have been adopted in the United States if the Morse alphabet had not already obtained such extensive use among operators.

The only codes that are in general use are the Morse and the International Morse. Either of these codes may be used in wire or radio telegraphy, yet each has been adopted in certain particular fields. In some fields, such as railroad work where both wire and radio systems are employed and the Morse code is used in the wire system, it is sometimes convenient to use the Morse code also for the radio system.

CODE-PRACTICE APPARATUS

KEYS

GENERAL USES

8. The signals transmitted in telegraph systems consist of proper groups of current impulses. A **key** is the device used in telegraphy to open and close the electric circuit and thus form the current impulses which are transmitted through the line. The current impulses acting on the receiving device produce the signals or dots and dashes of the various codes. The receiving operator translates the signal combinations into the proper characters, or they may be recorded on some type of *automatic recorder* and later transcribed into message form.

9. Keys such as are used in wire telegraphy are satisfactory in radio work where the current to be broken is not too large. The current used in wire telegraphy is very small, and the *contact points* which actually make and break the circuit are correspondingly small. The interrupted current in radio practice is often many times greater than that used in wire telegraphy, hence larger contact points are necessary.

10. The downward stroke of the key is often called the *make*, and the upward stroke, the *break*, referring, of course, to the making and breaking of the circuit. The contacts on most good keys were formerly made of platinum, because of the ability of that metal to resist better than most other metals the corroding and fusing action of the electric arc that is always formed at the break. The scarcity of platinum and consequent advance in price has been instrumental in causing the adoption of silver as the metal from which the contact points are made. Silver contacts must be larger than those of platinum for the

same current capacity, as the former do not stand up quite as well as the latter. When the silver contact points are properly designed and of ample size, they have been found to give good service. Various other metals are used for contacts in the many different types of keys, and are listed under numerous trade names.

ONE TYPE OF TELEGRAPH KEY

11. A type of key extensively used, particularly in wire telegraphy, is shown in Fig. 1. It consists of a steel lever *l* and trunnion, all in one piece, and pivoted in trunnion screws *c*, which are mounted in standards projecting upwards from the brass plate *m*. Locknuts *c′* bind the trunnion screws in any

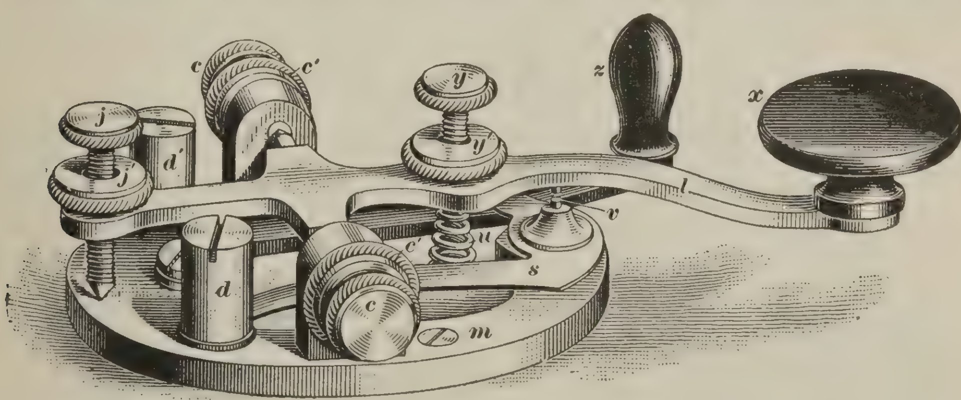


Fig. 1

position to which they have been adjusted. A coiled spring *u*, which may be adjusted by the screw *y* and secured by the locknut *y′*, presses the forward end of the lever upwards. The upward movement of the forward end of the lever is limited by the screw *j*, and the latter is held securely in position by the locknut *j′*. As the handle, or button, *x*, made of insulating material, is pressed down, a contact point carried on the under side of the lever, makes contact with a point *v* carried on, but insulated from, the base *m*. This lower contact point, or anvil, is in metallic connection, by means of a flat strip of metal *s*, with the binding post *d*, which is also insulated from the base plate *m*. The other binding post *d′* is connected directly to the base plate. These binding posts *d* and *d′* form the terminals of the key.

12. The path through the instrument may be traced as follows: From the binding post *d*–strip *s*–lower contact point *v*; then, when the key is depressed, to the upper contact point–the trunnion–trunnion screws and spring *u*–base plate *m*–binding post *d'*. The switch handle *z* is connected with a metallic arm called the *circuit closer*, pivoted directly on the base *m*, and, when pressed toward the key lever *l*, makes contact with an extension of the strip *s*, thus short-circuiting the key. The circuit closer in wire telegraphy is used to close the current through the home key when the key at another station is sending impulses over the line. When this key is used in radio work, the circuit closer should be left open at all times or it may be detached from the base.

SMALL-CAPACITY RADIO KEY

13. A type of key suitable for use in small-power radio stations is shown in Fig. 2. The essential parts of this key are not radically different from those of the key which has been described. It will be noted that the key as a whole is of rather rugged construction, so it may stand up well under rough usage. The lever *a* carries a comparatively large contact point at *b* which closes the circuit through a stationary contact point just below *b*. The base *c* is made of bakelite dilecto, which material has been found entirely satisfactory for that purpose and considerably cheaper than brass. The lower stationary contact is connected directly to one of the binding posts by a conductor underneath the base. The circuit from the upper contact at *b* is through the lever, thence through a flexible copper braid *d* and a connection under the base to the other binding post. The reason for using the copper braid is that a low-resistance connection is assured between the lever and the binding post. With fairly large currents it is not con-

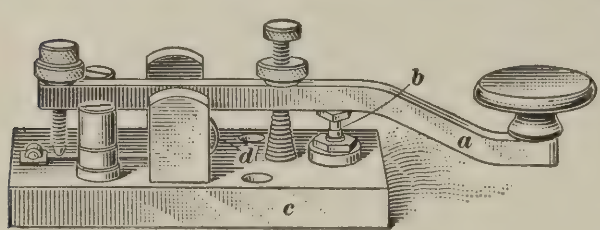


FIG. 2

sidered good practice to rely on the path through the trunnion and trunnion mounting to carry the current, as that path is liable to introduce a high resistance.

LARGE-CAPACITY RADIO KEY

14. A key of somewhat similar design is shown in Fig. 3. The lever *a* carries a very large contact *b*, indicating that this key is designed for interrupting quite large currents. The base *c* is made of bakelite dilecto, with countersunk screw holes to hold screws for fastening the base to a table. A heavy copper braid *d* is provided to carry current from or to the lever arm. The length of the air gap between the contacts may be adjusted by screw *e*. The rapidity with which the lever opens the circuit

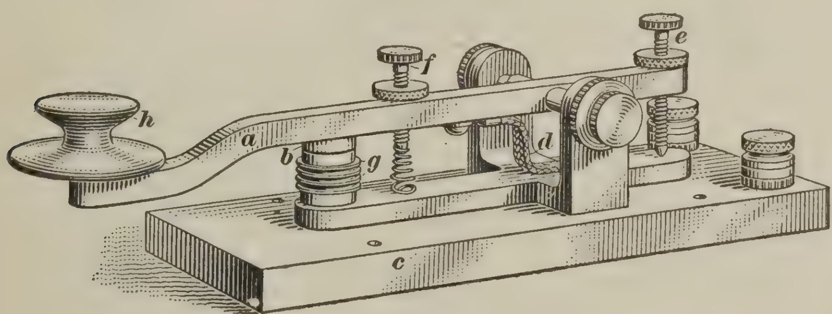


FIG. 3

depends largely upon the setting of screw *f*, acted upon by the spring immediately below it. The gap must be opened far enough to break the circuit completely, and the more rapidly this is done the better.

15. The contact points are apt to become heated to a considerable extent when the key is used to carry and interrupt large currents. Making these points of large dimensions assists materially in the dissipation of the heat produced. In this key auxiliary cooling flanges *g* are provided which offer a large cooling surface and are, therefore, instrumental in radiating a large part of the heat. Keeping the contact points at a fairly low temperature has been found helpful in breaking the arc quickly. The handle *h* of the key is fitted with a safety disk to prevent the operator's hand from accidentally touching the metal lever.

RELAY KEY

16. A **relay key** is an electromagnet so arranged that movements of its armature open and close an electric circuit. This circuit may or may not be separate electrically from the circuit that supplies current to the winding of the relay. The electromagnet is usually so constructed that it operates with a very low current and a hand-operated control key can be used with safety to control the low-voltage, low-current exciting circuit. The armature of the relay is capable of controlling a circuit of such voltage and current as to make it undesirable to use a hand-operated key. In many cases it is desirable to control the main circuit by a control key placed some distance

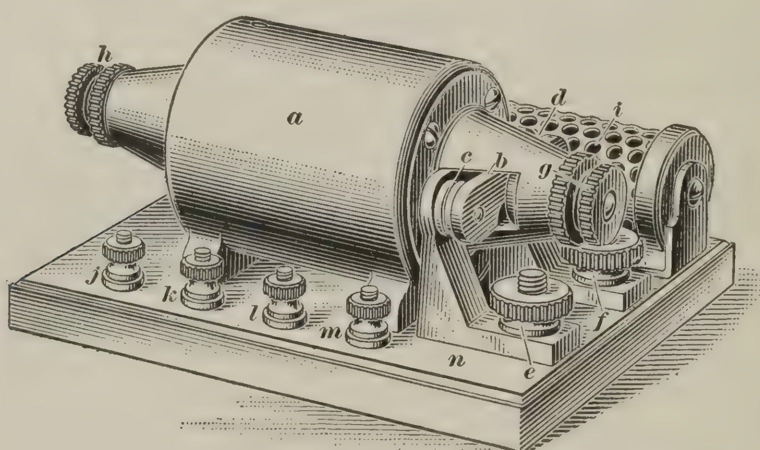


Fig. 4

from the relay key, thus making it unnecessary to extend the main-circuit wiring to the point of control.

The circuit including the operating key and relay winding is called a *local*, or *auxiliary*, circuit, to distinguish it from the main circuit, which is controlled by the armature of the relay.

17. A **relay key** such as used in radio telegraphy is shown in Fig. 4. Fig. 5 shows a wiring diagram of this relay key connected to the operating key of the local circuit. Corresponding parts of the device are lettered in a similar manner in both figures. In Fig. 4 the relative positions of the parts of the device are shown, and in Fig. 5 the wiring within the protecting shells is indicated. The electromagnet is shown at *a*

and the iron plunger at *b*. When the coil *a* is excited, the plunger *b* is drawn into the coil and the contact points at *c* and *d* are closed. These main contact points are connected to binding posts *e* and *f* which serve as terminals for the heavy-current circuit from point *e* through *c*, *b*, and *d* to terminal *f*. It should be noted that there are two points at which the circuit is opened and closed. This arrangement insures a more rapid break and also reduces sparking and heating by dividing the arc. Thus, a larger current may be interrupted than would be possible if a single contact were used.

18. A spring connected to the adjusting and locking nuts at *g* is placed under tension when the plunger is drawn up to

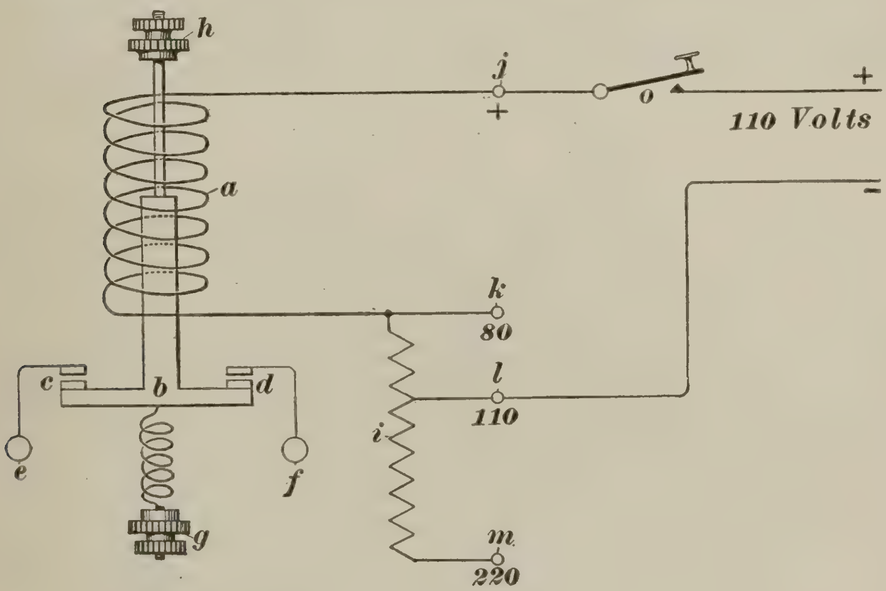


FIG. 5

close the circuit, and promptly withdraws the plunger when the coil *a* is deenergized. The distance to which the plunger is *withdrawn* depends upon the adjustment of the nuts at *h* which screw on an extension of the plunger core. The air gaps at *c* and *d* need only open far enough to insure that the arc will be suppressed with every opening of the contact points. Also the tension of the spring should not be such that the plunger does not have time to close the main contacts before coil *a* is demagnetized during rapid sending.

A resistance coil *i* permits the use of this relay key on several different operating voltages. The positive side of the control circuit is connected to terminal *j*, and the negative side to the proper one of the terminals *k*, *l*, and *m*. The coil itself may be operated satisfactorily on 80 volts, but for higher voltages it is necessary to use all or part of resistance *i*. No special internal connections are necessary for operation at the higher voltages; it is merely necessary to connect the line to the terminals marked for that particular voltage. The device is mounted on an insulating base *n* and makes a very compact unit, as shown in Fig. 4. Fig. 5 shows how a small key *o* is connected in series with coil *a*, the whole being connected for operation from a 110-volt, direct-current supply circuit. Closing key *o* excites coil *a* which attracts plunger *b*, thereby closing the circuit between terminals *e* and *f*.

TROUBLES OF KEYS

19. When a key, on rising, does not break the circuit, it is said to *stick*. This sticking may be due to any one of several causes. The principal cause is the fusing action of the electric spark at the contact points, but it may be caused by metallic dust collected on and bridging over the contact points, or by an improper adjustment that causes the points to come together improperly and bind. The contact points, therefore, should be kept clean by drawing between them a piece of hard, clean paper or fine emery cloth, or they may be rubbed very gently with a very fine file and then wiped clean. Frequent use of the file or emery paper, however, should be avoided.

Pivot, or trunnion, screws often become loose and cause trouble; to prevent this they should be kept as tight as is consistent with a free and easy movement of the key. Loose connections are frequently the cause of poor and irregular signals, but with frequent inspections little trouble should be experienced from this source.

SIGNAL-RECEIVING APPARATUS

WIRE-TELEGRAPH SOUNDERS

20. Signals in wire telegraphy consist of impulses of current sent over the line whose circuit includes a suitable electromagnet. The operation of the key causes the interruptions in the line current. One type of signal-receiving apparatus consists of a special form of electromagnet with its auxiliary devices and is called a **sounder**, because of its ability to produce audible signals when energized by a flow of electricity through its windings.

21. One type of sounder, which is shown in Fig. 6, represents the main features common to this apparatus. The wind-

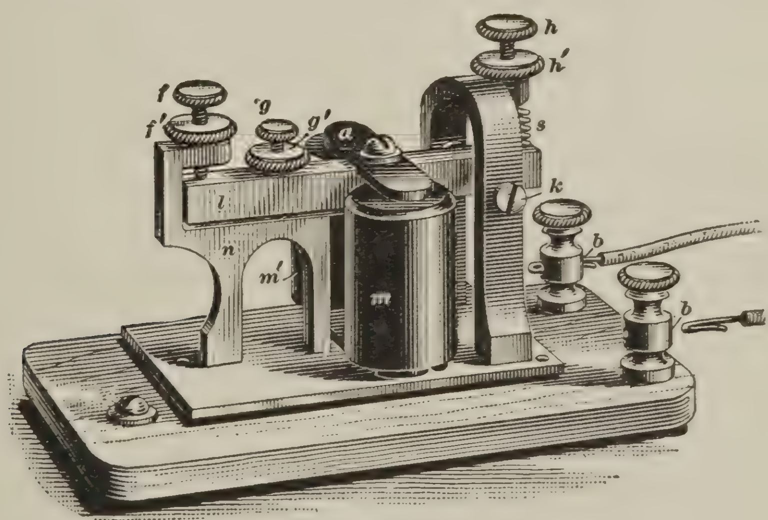


FIG. 6

ings of the two magnets are mounted on iron cores and protected by hard-rubber casings m and m'. An armature a of soft iron is mounted on a brass or aluminum lever l which is pivoted between the trunnion screws k. The armature is normally held in its upper position by means of the compression spring s. which bears down on the short end of the lever l, the compression of the spring being regulated by the thumbscrew h and locked, after adjustment, by the locknut h'. The downward

stroke of the lever is limited by the lower end of the screw *g* striking against the anvil *n*; and the upward stroke is limited by the lever striking against the lower end of the screw *f*. The play of the armature can therefore be adjusted by means of the screws *f* and *g*, and, after the proper adjustment is obtained, it can be made permanent by the locknuts f' and g'. The binding posts *b* form the terminals of the circuit through the coils, the current passing through them in series so as to make the upper pole of one iron core have north polarity and the upper pole of the other core have south polarity. The sounds given out by the sounder may be augmented by mounting the instrument on a sounding board. The metal base plate and the wooden base are usually constructed with this idea in view, and, for this reason, are slightly separated.

22. Direct current is used in wire telegraphy; hence the armature strikes the anvil when the current is established, and strikes a second blow on its back stop when the circuit is broken. The interval between the successive strokes enables the operator to determine the length of the signal. For example, a dot would be represented by a downward stroke immediately followed by an upward stroke of the armature. A longer interval of time between the two strokes indicates a dash.

Alternating current of a rather high frequency is generally used in radio work. When alternating-current impulses are received, the signals give a buzzing or humming tone; the relative duration of the sound indicating the length of the transmitted signal or impulse. The sounder, with its rather heavy armature, does not readily respond to these rapid pulsations of current. The main factor that prevents the use of sounders in this field, is that the received current is so weak that it cannot produce the required magnetic strength, and an entirely different system of rendering the current impulses audible has been developed.

BUZZERS

23. A **buzzer** is an electromagnetic device which emits a buzzing sound when current is established through it. The tone is similar to that produced in a telephone receiver by radio signals and it is, therefore, common practice to use a buzzer in learning the International code. There is a considerable difference between the sound of the buzzer and that of a sounder, but a professional telegraph operator can usually receive radio signals after a short period of practice. The ordinary buzzer resembles the sounder in that an electromagnet, when excited, attracts an armature of rather light weight. The buzzer, however, is provided with a circuit-breaking device which breaks up the received current into still smaller impulses, thereby causing a rapid vibration of the armature.

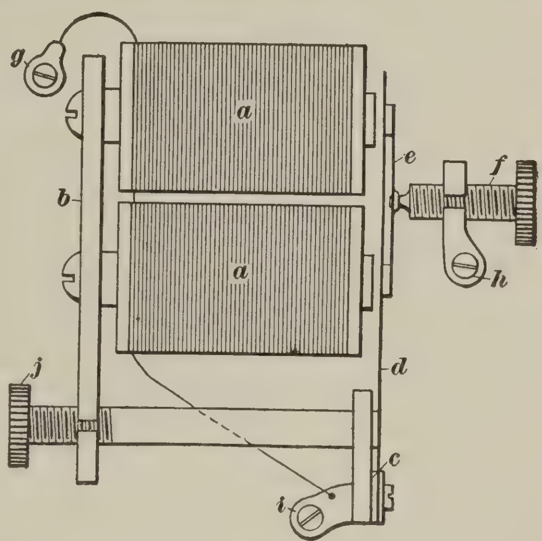


Fig. 7

24. Principle of Operation.—Fig. 7 shows the arrangement and connections of the parts of a buzzer. Fig. 8 shows

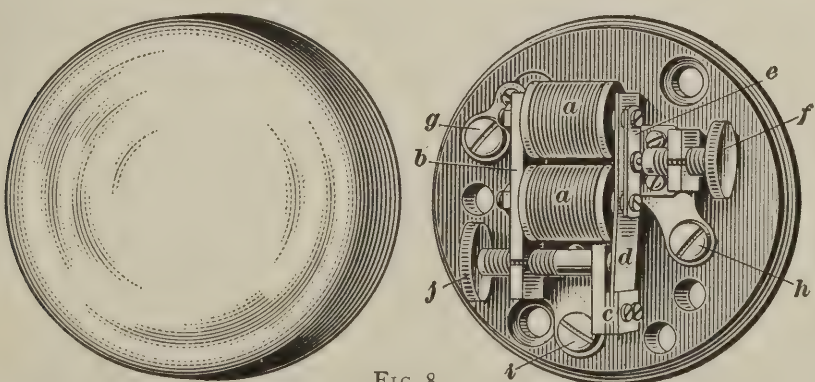


Fig. 8

an assembled view. Similar reference letters apply to both figures. The magnet windings are shown at *a* and their iron

cores are supported rigidly by the iron yoke *b*. A support *c* holds firmly one end of the vibrator spring, or armature, *d*. The armature near its free end carries a small spring *e* at the center of which a contact point is mounted. When the buzzer magnets are deenergized, this contact is pressed against the contact mounted at the end of screw *f*. The main terminals of the buzzer are shown at *g* and *h* and an auxiliary terminal at *i*.

Adjustment of screw *j*, which presses against the armature *d* near its fixed end, changes the tone of the buzzer. Adjustment of screw *f* serves to make up for the gradual burning of the contacts and to a certain extent changes the frequency of the vibrations of the armature. The holes in the supports for screws *f* and *j* are made slightly small; slots are cut to the holes and when the screws are inserted, a tight fit is assured which is relied upon to hold the screws in adjustment without the use of locknuts.

25. The operation of the buzzer is independent of the direction of the current through its windings. The current enters, say at *g*, and passes through the device by way of the magnet windings *a*–mounting *c*–the spring *d*–spring *e*–contact point on spring *e*–point and body of screw *f*–through mounting of screw *f*, and out at terminal *h*. As soon as current is established through coils *a*, the armature *d* is drawn toward the magnets. This movement of the armature causes the contact points to separate and open the circuit between *e* and *f*. The opening of the circuit cuts off the current and the armature is released. The springiness of armature *d* causes its free end to fly back and the circuit is reestablished through the contact points. This cycle of events is rapidly repeated and the vibration of the armature gives rise to the audible buzzing sound. Due to the light weight of the vibrating parts, the tone of the buzzer is quite high, and closely resembles that given out by a radio receiving set.

A terminal *i* may be used in connection with terminal *h* in case it is desired to connect only the circuit-breaking part of the buzzer in another circuit for special testing or other pur-

poses. It is, however, necessary to energize the magnets *a* through terminals *g* and *h*. The various parts of the buzzer are mounted on an insulating base shown in Fig. 8. Suitable holes are provided for mounting screws and for the entrance of connecting wires to the buzzer terminals when the cover is in place. A metal cover, Fig. 8, serves to provide mechanical protection to the device and also adds to its appearance.

26. There is, apparently, considerable variation between the types of buzzers made by the various companies, but the difference is chiefly one of design and in the arrangement of parts. The fundamental principle of operation remains the same in all of them despite the particular advantages of certain types. Numerous devices are in common use, by means of which the emitted tone of the buzzer may be varied until it gives out a clear high-frequency signal.

27. Applications of Buzzers.—The combination of a buzzer *a* and a key *b* properly connected to a primary cell *c* is

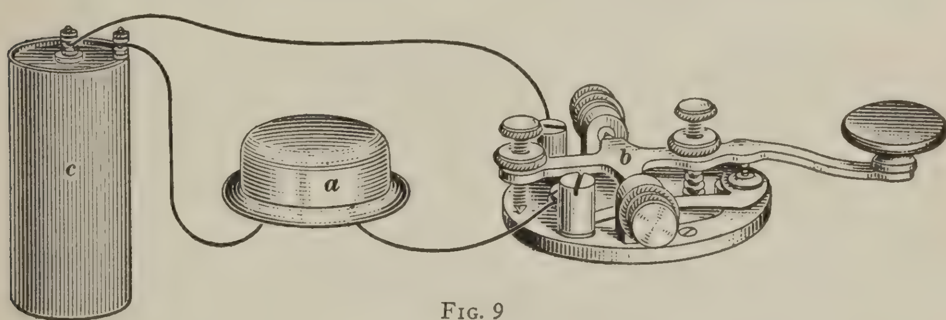


Fig. 9

shown in Fig. 9. This outfit is particularly suitable for learning the radio code. The judgment of the sender should not be relied upon, however, as to the accuracy of his signals. He may to his own satisfaction be sending perfect code, but it may be impossible for any one to read it.

Instruction in code practice is usually given by an experienced operator who sends the code characters. The student listens to the signals and endeavors to write the letters and figures corresponding to the characters sent by the operator. In order to give better practice it is desirable that the persons be located in different rooms or even in separate houses, and that

all communication between them should be by means of the code signals. This may easily be accomplished by connecting two keys, two buzzers, and a battery in series in a circuit connecting the two stations. It is necessary in this case to use keys with short-circuiting switches, such as regular wire-telegraph keys. This short-circuiting switch must be closed at one station when the other is sending, otherwise the circuit would be open at two places, and no signals could be transmitted. In case a key with a short-circuiting switch is not available, a good expedient is to short-circuit the terminals of the key which is not used by a short length of wire. When operating properly both buzzers respond to current impulses caused by the closing of one key. This arrangement of two outfits is somewhat inconvenient because no means of signaling are provided by which the operator who has left his short-circuiting switch open may be called.

28. When two or more instruments in the same house are to be connected, insulated copper wire, called annunciator, or office, wire may be used. A No. 18 Brown & Sharpe gauge copper wire will be about the right size. Insulated wire may be fastened in place by small staples, or double-pointed tacks, care being taken not to injure the insulation in any way. When joining the wire to a binding post, the end of the wire should first be made clean and bright, then placed in the hole in the binding post, and firmly fastened there by the screw. Do not allow the bare end of a wire to touch anything except the binding post or another wire to which it is intentionally joined. By wrapping 8 or 10 inches at the end of a wire in a close helix around a lead pencil, and then sliding out the pencil, a neat springy coil can be made, by means of which no slack need be left in the wiring, and it will give a finished appearance to the connections.

29. Because of their great convenience, dry cells are in quite common use with beginners' sets as a source of electromotive force. Some types of wet cells are used in large installations where the item of cost is an important one. It must always be remembered, when connecting cells in series, that

they should be so connected that their voltages add or assist each other. This is particularly important where two or more batteries are located at different points in the same circuit, as one reversed battery will not only be of no value in that circuit, but will oppose part or all of the electromotive force established by the other batteries.

30. The use of telephone receivers for the reception of radio signals is quite common. In order to give practice in this method of receiving, it is customary to use telephone receivers for a portion of the training period, if not exclusively. They also help to exclude outside sounds by being held against the ears, which enables the person receiving to concentrate on the incoming signals. The principles of operation of telephone receivers will be covered in a succeeding Section.

OPERATING HINTS

LEARNING TO SEND

METHOD OF HOLDING KEY

31. The first step in learning to send telegraph characters is to develop complete control of the hand. The key should be located on the table in such a position that when the hand is placed on the key, the arm will assume the normal writing position. This arrangement will be much less tiring than if the hand and arm were placed in an unnatural position. A good position for holding the key is shown in Fig. 10; it is the one adopted by many of the most speedy and perfect operators. Rest the first finger on the top, near the edge, of the key button, with the thumb and the second finger against the opposite edges, as shown. Curve the first and the second finger so as to form the quarter section of a circle. Avoid straightness or rigidity of these fingers and the thumb. Partly close the third and the fourth fingers.

32. Many operators prefer to rest both the first and second fingers upon the key handle or button, with the thumb and third finger pressing lightly upon opposite sides of the button. This method is perhaps preferable, especially in the operation of large keys. The thumb and fingers should always remain in contact with the handle, but still must be kept flexible enough to form a sort of spring action between the rigid key and the hand. The elbow should rest easily on the table at all times, and the wrist should be elevated from the table and perfectly

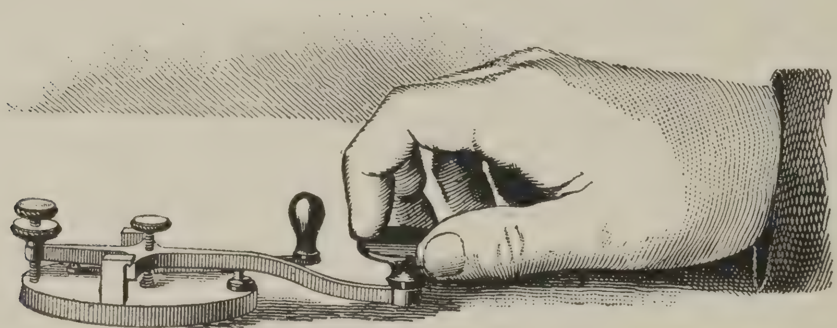


FIG. 10

flexible. The key is operated by a free and easy motion of the whole forearm rather than by motion of the wrist alone. The motion should be directly up and down, avoiding all side pressure. When the proper swing is acquired, the forearm moves freely in conjunction with the wrist and fingers. The grasp on the button should be moderately firm, but not rigid. Grasping the knob tightly will quickly tire the hand and destroy control of the key, causing what is termed telegraphers' cramp.

ADJUSTMENT OF KEY SPRING

33. In the matter of adjusting the spring of the key, there is considerable difference of opinion. It is a good rule to avoid too much force or too light a touch, and to strive for a medium firm closing of the key. It is not the heavy pressure on the key, but the evenness of the stroke that constitutes good sending. A few of the very fastest senders use very stiff springs, while many other fast senders use springs that are barely strong enough to keep the weight of the key from closing

the contacts. Some operators even use a spring which will not of itself open the key, in which case the thumb must be used to raise the key. A moderate amount of play and a medium pressure of the spring should be used by the beginner unless he has good reason to believe another adjustment more suitable.

CODE CHARTS

34. Code charts are introduced at this point in the text so that reference may be easily made to them in connection with the suggestions for sending the characters. The first code chart includes the characters for letters and figures for the International Morse and the Morse codes. The second code chart includes the characters for punctuation marks for the International Morse code, the Phillips code, and special International Morse code signals.

LENGTH OF DOT, DASH, AND SPACE

35. In all codes, the dot is taken as the unit by which the lengths of the dashes and spaces are measured. The generally accepted relative lengths of the different dashes and spaces, some of which are used only in the Morse code, are as follows:

Signal		Duration of Signal
Dot	1	1 unit
The dash	3	3 units
The long dash (*l*)	6	6 units
The extra-long dash (naught)	9	9 units
Space between parts of a character	1	1 unit
Space in spaced characters	2	2 units
Space between characters	3	3 units
Space between words	5	5 units

36. The dot, which also represents the character *e*, is made by a single instantaneous downward stroke of the key followed immediately by an upward stroke. The actual time required in making the dot will vary with the speed of signaling, but it

ALPHABETS

Letters	International Morse	Morse
A	· —	· —
B	— · · ·	— · · ·
C	— · — ·	· · ·
D	— · ·	— · ·
E	·	·
F	· · — ·	· — ·
G	— — ·	— — ·
H	· · · ·	· · · ·
I	· ·	· ·
J	· — — —	— · — ·
K	— · —	— · —
L	· — · ·	———
M	— —	— —
N	— ·	— ·
O	— — —	· ·
P	· — — ·	· · · · ·
Q	— — · —	· · — ·
R	· — ·	· · ·
S	· · ·	· · ·
T	—	—
U	· · —	· · —
V	· · · —	· · · —
W	· — —	· — —
X	— · · —	· — · ·
Y	— · — —	· · · ·
Z	— — · ·	· · · ·
&		· · · ·

NUMERALS

Figures	International Morse	Morse
1	· — — — —	· — — ·
2	· · — — —	· · — · ·
3	· · · — —	· · · — ·
4	· · · · —	· · · · —
5	· · · · ·	— — —
6	— · · · ·	· · · · · ·
7	— — · · ·	— — · ·
8	— — — · ·	— · · · ·
9	— — — — ·	— · · —
0	— — — — —	———

PUNCTUATION MARKS, ETC.

Characters		International Morse	Phillips Punctuation Used With Morse Code	
.	Period	· · · · · ·		· · — — · ·
:	Colon	— — — · · ·	K O	— · — · ·
;	Semicolon	— · — · — ·	S I	· · · · ·
,	Comma	· — · — · —		· — · —
?	Interrogation	· · — — · ·		— · · — ·
!	Exclamation	— — · · — —		— — — ·
— /	Fraction line	— · · — ·	E U T	· · · — —
—	Dash		D X	— · · · — · ·
-	Hyphen	— · · · · —	H X	· · · · · — · ·
'	Apostrophe	· — — — — ·	Q X	· · — · · — · ·
	Underline (or Italics)	· · — — · —	U X	· · — · — · ·
	End of underline	· · — — · —	U J	· · — — · — ·
(	Parenthesis (start)	— · — — · —	P N	· · · · · — ·
)	End of parenthesis	— · — — · —	P Y	· · · · · · · · ·
"	Quotation marks (start)	· — · · — ·	Q N	· · — · — ·
"	End of quotation	· — · · — ·	Q J	· · — · — · — ·
=	Double dash (or break)	— · · · —	B K	— · · · — · —

SPECIAL INTERNATIONAL MORSE CODE SIGNALS

Conventional Signals

Attention call, to precede every transmission	— · — · —
General inquiry call	— · — · — — · —
From (de)	— · · ·
Invitation to transmit (go ahead)	— · —
Warning (high power)	— — · · — —
Wait	· — · · ·
Understand	· · · — ·
Error (series of dots)	· · · · · · · ·
Received (O. K.)	· — ·
Transmission finished (end of work)	· · · — · —
Distress call	· · · — — — · · ·

Special Letters

Ä (German)	· — · —
Á *or* À (Spanish-Scandinavian)	· — — · —
CH (German-Spanish)	— — — —
É (French)	· · — · ·
Ñ (Spanish)	— — · — —
Ö (German)	— — — ·
Ü (German)	· · — —

is important that the relative lengths of the dots, dashes, and spaces should remain constant. There are four lengths of spaces and three of dashes, or, including the dot, four.

A dash, or the letter *t*, is made by holding the key down as long as it takes to make 3 dots. This should be timed so that the duration of the signal transmitted is actually 3 times as long as that sent as a dot. The space or interval of time between characters should equal 3 units. It will then be exactly like the dash in length of time. The space between words or groups of characters should be made equal to 5 units. This spacing is very distinct and enables the operator to separate the letter and number groups of characters very readily even when receiving code words such as are used for secret communications.

37. Some characters which are used only in the Morse code have special lengths of dashes and spaces. A long dash is used to represent the letter *l*, and is made 6 units long. An extra long dash, normally 9 units in length, designates the figure *0* (naught). However, in practice, the *l* and the *0* are often made 5 and 7 units long, respectively. In many cases the *l* and the *0* (naught) are made the same; occurring alone, the long dash would be read as *l*, but when found among figures it would be translated as *0* (naught). Reducing the length of all dashes allows a little greater speed in transmission, but is not desirable where recording instruments are used.

The space in the *spaced letters* of the Morse code, *C*, *O*, *R*, *Y*, *Z*, *&*, is 2 units long, or just double that ordinarily used between the elements of a letter. In case the receiving is rather poor, it is sometimes difficult to distinguish the 2- and 3-unit spaces because of the relatively small difference between them.

PRACTICE WITH THE KEY

38. Begin the use of the key by making dashes in succession, first at the rate of about one a second, and then gradually increasing to two or three. Care should be taken to make the break between the dashes quite short, for there is always a

tendency to make too large a space between dashes, and this should be guarded against.

The dots should be made as regularly as possible, and at the rate of about five a second, and the speed increased with practice; but, no matter how fast the dots are made, they should be regular, definite, and uniform.

Sending is not merely making the dots and dashes as arranged on the code chart. It involves the accurate timing of the dot and dash signals, and of the spaces and intervals between individual elements of the characters. In accordance with these views, it is desirable to practice on the following exercises in the order given. In each exercise, after learning to make each character correctly without hesitating, write them in succession, both forwards and backwards, until able to do so without having to repeat a single character before proceeding to the next. The characters in the following examples relate to the International Morse Code.

DASH CHARACTERS

t	*m*	*o*	*0*
—	— —	— — —	— — — — —

39. The tendency to prolong the final dash or dot can be overcome by making it with a movement apparently a little quicker than that used for the preceding dash or dot. In making characters containing a succession of dashes, care must be taken to have them follow one another as closely as possible; too much space is apt to be put between dashes.

DOT CHARACTERS

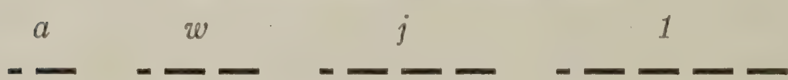
e	*i*	*s*	*h*	*5*
·	· ·	· · ·	· · · ·	· · · · ·

40. Practice each one of these characters until the right number of dots can be made for each one almost unconsciously, being careful at the same time to make all dots of equal duration and not to prolong the last dot into a dash.

DASH-AND-DOT CHARACTERS

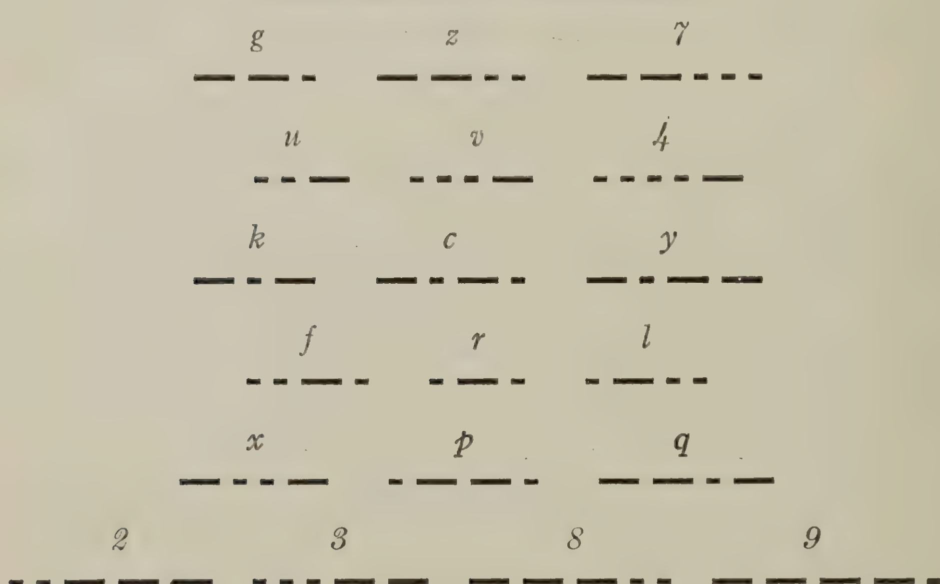
41. There is a great tendency to make the break between the dash and the dot too long; should this be done, for instance, in making the letter *n*, *te* is made instead of *n*.

DOT-AND-DASH CHARACTERS



42. When making each of these characters, let the dash signals follow the preceding dot closely, and avoid making the dashes improperly.

MISCELLANEOUS CHARACTERS



SPACED CHARACTER

. (Period)

- -   - -   - -

43. When making the period, the space between each pair of dots should be just double that allowed between the elements of each pair. Avoid making this space too long, as there is more likelihood that it will be made too long, rather than too short.

RESULTS OF IMPROPERLY MADE CHARACTERS

44. In the following lines, the first two characters, improperly connected by too short an interval, will make the third character. Thus, if *a* and *t* are connected by too short an interval, *w* will be made; and if *e* and *d* are made with too short an interval between them, an *l* will be made, and so on.

a	*t*	*w*	*e*	*d*	*l*
- ——	——	- —— ——	-	—— - -	- —— - -
u	*e*	*f*	*d*	*e*	*b*
- - ——	-	- - —— -	—— - -	-	—— - - -
i	*t*	*u*	*m*	*a*	*q*
- -	——	- - ——	—— ——	- ——	—— —— - ——

45. The following exercise shows that if the last dot in the characters given is carelessly prolonged into a dash, the character following it will be made instead of the one intended. Other examples could have been used to show a similar effect.

i	*a*	*s*	*u*	*h*	*v*
- -	- ——	- - -	- - ——	- - - -	- - - ——
5	*4*	*n*	*m*	*r*	*w*
- - - - -	- - - - ——	—— -	—— ——	- —— -	- —— ——

46. If the final dash in *k* is made too short, *d* will be formed, and if too much space is made before the final dash, *nt* will be formed. Similarly, too much space before the second dash in *c* (—— - —— -) will transform it into *nn* (—— -   —— -). Many other examples of common errors in sending could be

mentioned, but those given will serve to illustrate the necessity for accuracy in the transmission of code signals. In many cases the receiving operator can tell from the meaning of the word or message what the missing or incorrect character should be, but this does not excuse the inaccuracy of the sender.

47. The following words may be used when learning the code. It is well to make up additional groups of words for practice, starting with words represented by a few simple or short signals, and advancing through longer words as progress continues.

And

.— —. —..

Humane

.... ..— —— .— —. .

Judgment

.——— ..— —.. ——. —— . —. —

Limited

.—.. .. —— .. — . —..

Maintain

—— .— .. —. — .— .. —.

Barn

—... .— .—. —.

Chair

—.—. .... .— .. .—.

Desire

—.. . ...—. .

Exchange

. —..— —.—. .... .— —. ——. .

Family

..—. .— —— .. .—.. —.——

Terminate

— . .—. —— .. —. .— — .

Umbrage

..— —— —... .—. .— ——. .

Vacant

...— .— —.—. .— —. —

Warrant

.—— .— .—. .—. .— —. —

The following also are good words on which to practice: *Let, little, take, train, jaw, knoll, knot, need, nod, ice, rice, person, poison, Mississippi.* Be careful to make *an, c, h, i, k, s,* and *th* correctly, in order to avoid their being taken for other characters, as previously indicated.

48. Each word of these groups should be repeated until each character in them can be made at will. The beginner should be careful to form each character correctly, because this will lead to a perfect style in sending. Operators have almost as many styles of sending as there are styles of penmanship. When these groups have been mastered, the transmission of short sentences may next be taken up. Care must always be taken to write one sentence correctly before another is attempted.

49. In some cases, the code is taught by starting with characters represented by the least number of dots or dashes. Progress then is continued through the code, starting with the simpler combinations and advancing through the more complex characters until finally all can be made with equal ease. The beginner should start by making the letters *e, t, i,* and *m* correctly, after which the slightly more difficult combinations, as *n, a, s, h, o,* and *r*, should be taken up and mastered. Practice in sending words made up of groups of these letters would help to fix the groups in mind. The practice with the simpler characters helps to some extent to master the more complex ones. The student can easily assemble the letters made up of simple dot and dash combinations into short words. Practice with short word groups, such as *at, me, bat, dot, eat, him, date, met, tie, moose,* and *home*, followed by the more advanced word groups, will be the plan to follow in this method.

50. Accuracy More Desirable Than Speed.—A firm, even, smooth style of sending should be cultivated. At first, accuracy rather than speed is desirable. The practice of timing in order to ascertain the speed of sending should be very sparingly indulged in by the beginner, for this practice is conducive to careless habits. The speed of sending should be graduated to suit the capacity of the receiver; the latter should never be

crowded. Strictly first-class work will not be required in the first position obtained by the operator, but he must be reliable. It is well to remember that an operator is no judge of his own Morse, and therefore should not try to see how fast he can send until he has had considerable experience. Fast sending is seldom indulged in by strictly first-class operators, but fast time is made by them on account of their steady, even gait, their perfect characters, and few repetitions or mistakes. The average receiver's opinion in regard to sending should be accepted before a person decides for himself that his sending is all right, for the poorest operators often believe that their sending is good. If the receiver complains that the operator does not space properly, or calls attention to some particular fault, he should not get angry. On the other hand, he should take the hint, and try to remedy all weak points.

51. In code practice, when slow sending is necessary, the elements of the characters should not be drawn out. They should preferably be sent at a moderately fast rate, the different sending speeds being obtained only by varying the interval between characters and their groups. If the elements of a character are changed by lengthening the resulting group signal sounds different than if the same characters were properly sent.

LEARNING TO RECEIVE

52. To learn to receive, it is necessary to have another person manipulate the key, or an automatic sending device to produce the characters, for one cannot read by sound from his own sending. It is very desirable that the sender should be able to make the signals distinctly and correctly, otherwise it will be very difficult, if not impossible, for the learner to understand the signals. However, two beginners can get good practice by taking turns at sending and receiving, each correcting the faults of the other.

53. There is considerable variation in the tone of different stations, depending largely on the type of transmitting apparatus. This is found to give very little trouble in actual

practice. In fact this feature is in many cases desirable as it enables an operator to distinguish between separate stations which may be operating at the same time. The sounds produced by the buzzer depend upon the length of the signal and the length of the spaces, or intervals between signals. The sounder used in wire telegraphy is different, in that the letter or character is determined solely by the time or times the lever strikes the bottom and top stops, and the duration of time between these clicks. No sound is emitted excepting at the beginning and end of the dot or dash. The buzzer, on the other hand, operates throughout the length of the dot or dash, and, for that reason, is in many cases, easier to read.

54. A learner should begin to read by sound by receiving letters and copying them. He should continue this exercise until each letter is instantly recognized. It is not well for a beginner to wait for whole words; each letter should be written down as soon as it is received, for if he waits for the whole word he is apt to become confused and fail to get the word, thus causing him to guess at it. He should learn to listen and write at the same time, and after he is proficient in receiving and writing letters he should practice on words and sentences. The speed of receiving and copying should be gradually increased until both can be done rapidly.

The beginner should thoroughly study the International Morse alphabet and memorize it perfectly before making an attempt to copy from a sounder or an automatic transmitting device. Many learners require a longer time than necessary to become fair operators on acccount of failure to understand and memorize the proper signal combinations representing the telegraph characters. In some cases, it may assist the beginner to copy every other word of the message from a fast sender. This will give very good practice, and the number of letters received may be increased until all are copied correctly.

55. An operator should learn to copy that which is sent him as far behind transmission as possible. Although this will be hard to do, especially at the beginning, because it divides the attention and requires the exercise of memory, it must be

accomplished before one can become a good receiver of rapid sending. The beginner will find it difficult at first to keep one or two words behind, but improvement will come by practice.

AUTOMATIC SENDING AND RECEIVING APPARATUS

56. Several types of automatic sending and receiving devices are in successful operation. Some of these are built primarily for the instruction of the beginner, while others are designed for operation in the transmission and reception of commercial messages. A device which will record signals sent is of benefit to a beginner as he can check over the message to see that the elements of the characters were properly made. An automatic sending device is also an advantage, even though it is mechanically operated, as the signals it makes must be accurately spaced.

57. In one method by which commercial messages are sent automatically, a special typewriter which makes perforations in a paper tape is used. The arrangement of the perforations will represent the characters of the telegraph code. The perperforated tape is fed at high speed through a circuit-closing device which sends out signals at a higher rate than could be accomplished by manual sending. A special receiving apparatus records the incoming high-speed signals on another paper tape by making corresponding perforations thereon. This tape may then be run through a signaling device which will produce audible signals at a convenient speed for the operator to receive and copy.

58. Many other methods of sending and recording signals automatically are in use. A description of the principles of operation of any special type of apparatus is usually furnished with that device. A careful study of the instructions will reveal the proper method of operation. The chief advantage of these devices is that they permit the transmission and reception of a larger number of messages during a given time, with a

limited amount of apparatus. The additional care required and practicability of such devices should always be investigated when considering the adoption of such complex apparatus.

CODES OF ABBREVIATIONS

59. A telegraph **code of abbreviations** is a system of abbreviations, or a sort of shorthand applied to a means of communication. It usually consists of single letters and a combination of two or more letters, which arbitrarily represent figures, words, and phrases. Words and phrases in very common use are represented by single letters or short combinations of letters. In some cases, the communication companies, to save time, and for their own convenience transfer the message into code form. Because of the difficulty in memorizing a long list of abbreviations, the code message is usually recorded just as it is sent, no effort being made to copy the matter in full wording as it comes in. The message is later transcribed from the record and put out in regular message form.

These codes have come into very extensive use in wire telegraphy, especially in newspaper reporting. Such codes enable a person to send a rather long message in a few word groups, thereby reducing the cost considerably, as charges can be collected only on the amount of material sent. If desired, the message can be made relatively secret.

60. Several code systems have come into use, and by employing one of them it is possible to send a message very economically and with a fair degree of secrecy. One extensive and complete system arranged for the use of the public, is called the A B C code. By its use, a long messsage can be transmitted in a few words, and the cost of a message, which might otherwise be very expensive, can be made quite reasonable. It is published in book form, and both the sender and receiver must have a copy of the same code book, for the various communication companies will not form or translate the message. Each page in the book is divided into three columns. In the first column are figures from 1 to 99,999,

inclusive; in the second column are words or combinations of letters arranged alphabetically; and in the third column are placed the words, phrases, or sentences that the numbers or words in the first or second column represent. For example, suppose the body of a message to be cabled is as follows: *Tugs now assisting; we write you full particulars*, in which the important words are *tugs* and *write*. Looking these up in the code book, the lines containing them will be found to be:

14,643	*Turtle*	*Tug (s) now assisting*
15,419	*Worthily*	*I (we) write you full particulars*

The body of the message may then be written *Turtle Worthily*. The person receiving this message would then look up in his code book the meaning of the two words *turtle* and *worthily* and thus learn the meaning of the message. In this way, instead of eight words, only two have to be transmitted and paid for.

61. Cipher A B C Code.—Any one by using this code, can arrange a *secret and private cipher*. To do this, he should take ten letters, or, preferably, a ten-letter word in which the same letter does not occur more than once; such as the word *Cumberland*, and number each letter as follows:

c	*u*	*m*	*b*	*e*	*r*	*l*	*a*	*n*	*d*
1	2	3	4	5	6	7	8	9	0

In the first column of the code book, opposite the two phrases "Tug (s) now assisting" and "I (we) write you full particulars," are the two numbers 14,643 and 15,419, respectively. In the word "Cumberland," *c* represents the numeral 1, *u* the numeral 2, *m* the numeral 3, and so on. Thus, the number 14,643 is represented by the group of letters *cbrbm*, and the number 15,419 by *cebcn*. On the message blank, the sender using this cipher code would write, as the body of the message, the two following combinations of letters, for they are not apt to be words: *cbrbm* and *cebcn*.

These letters would be transmitted by the operator, in groups exactly as written, and the person to whom the message was addressed would first translate it into the two numbers 14,643 and 15,419 by means of the private code word "Cumberland" and the numerals corresponding to each letter in this word. Then, by looking up these numbers in the code book, the correct meaning would be obtained. Only the parties knowing what numeral corresponds to each letter in the code word can interpret the message.

62. If the code runs up to 99,999, that is, five figures, each combination of letters transmitted should contain five letters, and, therefore, if the number contains less than five figures, ciphers must be prefixed to make five figures. This is necessary, to avoid the risk of a wrong grouping of the letters by either the sending or receiving operator. For instance, suppose the word *best* were to be sent. In the code book would be found:

1,734	*Becalming*	*Best*

Now, 1,734 has only four figures in it, but five must be used. This is accomplished by prefixing a cipher to the set, which would give 01,734, and the corresponding combination of letters to be sent would be *dclmb*.

63. Toll Charges.—The company operating any station usually has certain rules concerning the counting of characters and words in determining the charge for the service. The operator accepting the message must determine the number of words or groups of characters on which the charge is based. In many cases a fee is charged for part or all of the address and signature as well as for the main part of the message. It is especially important that each letter, figure, and punctuation mark be transmitted exactly as it is written by the sender.

TABLE I

INTERNATIONAL RADIOTELEGRAPHIC CONVENTION LIST OF ABBREVIATIONS TO BE USED IN RADIO COMMUNICATION

Abbreviation	Question	Answer or Notice
PRB	Do you wish to communicate by means of the International Signal Code?	I wish to communicate by means of the International Signal Code.
QRA	What ship or coast station is that?....	This is........
QRB	What is your distance?..............	My distance is........
QRC	What is your true bearing?...........	My true bearing is........degrees.
QRD	Where are you bound for?............	I am bound for........
QRF	Where are you bound from?..........	I am bound from........
QRG	What line do you belong to?..........	I belong to the........Line.
QRH	What is your wave length in meters?...	My wave length is........meters.
QRJ	How many words have you to send?...	I have........words to send.
QRK	How do you receive me?.............	I am receiving well.
QRL	Are you receiving badly? Shall I send the signal (▬ ▬ ▬ ▬▬ ▬) 20 times for adjustment?..................	I am receiving badly. Please send the signal (▬ ▬ ▬ ▬▬ ▬) 20 times for adjustment.
QRM	Are you being interfered with?........	I am being interfered with.
QRN	Are the atmospherics strong?.........	Atmospherics are very strong.
QRO	Shall I increase power?..............	Increase power.
QRP	Shall I decrease power?..............	Decrease power.
QRQ	Shall I send faster?..................	Send faster.
QRS	Shall I send slower?.................	Send slower.
QRT	Shall I stop sending?................	Stop sending.
QRU	Have you anything for me?..........	I have nothing for you.
QRV	Are you ready?......................	I am ready. All right now.
QRW	Are you busy?.......................	I am busy (or: I am busy with.....) Please do not interfere.
QRX	Shall I stand by?....................	Stand by. I will call you when required.
QRY	When will be my turn?..............	Your turn will be No.........
QRZ	Are my signals weak?................	Your signals are weak.
QSA	Are my signals strong?..............	Your signals are strong.
QSB	Is my tone bad?..................	The tone is bad.
	Is my spark bad?.................	The spark is bad.
QSC	Is my spacing bad?..................	Your spacing is bad.
QSD	What is your time?..................	My time is........
QSF	Is transmission to be in alternate order or in series?	Transmission will be in alternate order.
QSG	....	Transmission will be in series of 5 messages.
QSH	....	Transmission will be in series of 10 messages.
QSJ	What rate shall I collect for?.........	Collect........
QSK	Is the last radiogram canceled?........	The last radiogram is canceled.
QSL	Did you get my receipt?.............	Please acknowledge.
QSM	What is your true course?...........	My true course is........degrees.
QSN	Are you in communication with land?..	I am not in communication with land.
QSO	Are you in communication with any ship or station (or: with........)?...	I am in communication with........ (through........).
QSP	Shall I inform........that you are calling him?	Inform........that I am calling him.
QSQ	Is........calling me?...............	You are being called by........
QSR	Will you forward the radiogram?......	I will forward the radiogram.
QST	Have you received the general call?....	General call to all stations.
QSU	Please call me when you have finished (or: at........o'clock)?	Will call when I have finished
*QSV	Is public correspondence being handled?	Public correspondence is being handled. Please do not interfere.
QSW	Shall I increase my spark frequency?..	Increase your spark frequency.
QSX	Shall I decrease my spark frequency?..	Decrease your spark frequency.
QSY	Shall I send on a wave length of ...... meters?	Let us change to the wave length of........meters.
QSZ	....	Send each word twice. I have difficulty in receiving you.
QTA	....	Repeat the last radiogram.
QTE	What is my true bearing?...........	Your true bearing is..degrees from...
QTF	What is my position?................	Your position is..latitude..longitude.

*Public correspondence is any radio work, official or private, handled on commercial wave lengths.

When an abbreviation is followed by a mark of interrogation, it refers to the question indicated for that abbreviation.

UNITED STATES GOVERNMENT PUBLICATIONS

64. The United States Government has entered into an agreement with other large governments of the world in adopting a certain list of abbreviations to be used in International Radio Communication. This list is printed in Table I. Slight revisions and additions are made from time to time to meet the requirements arising from change of conditions.

The distinct advantage of such a list of abbreviations is that it permits the exchange of ideas and information among persons who speak different languages. The well-known radio signal, *S O S*, used as a ship distress call, is, perhaps, the best illustration of the convenience of such a code. These abbreviations are in common use at nearly all radio stations.

This list, as well as much other information pertaining to radio communication, is contained in the pamphlet *Radio Communication Laws of the United States*. The book may be obtained from the Department of Commerce at Washington, D. C., at a nominal cost, and is of real value to one interested in radio communication. The pamphlet also contains regulations governing radio operators and the use of radio apparatus on ships and on land, a knowledge of which is necessary for any one who wishes to obtain a government license. Other authoritative information relative to the radio art may be obtained from the Government Printing Office.

RADIO DEVICES

(PART 1)

WAVES AND WAVE MOTION

PRINCIPLES OF WAVE MOTION

1. Wave motion of every form represents a transfer of energy. In the case of water waves, the motion and results produced by that motion may be observed by the eye. When a stone is dropped into water, the surface is immediately ruffled by waves which spread out in all directions. The water acts as a medium for the transfer of energy, and the waves will cause a stick floating on the water to bob up and down. Some of the work expended by the stone striking the water is thus transferred to the floating stick which moves in accordance with the disturbance on the surface of the water. If stones were tossed into the water at certain intervals a code of signals could be transmitted from point to point in this manner. Such might be said to represent briefly the principle of wave motion in radio communication.

2. Radio Waves Carried by the Ether.—A brief explanation has been given of the rôle played by the ether in the art of radio communication. Frequent reference to this medium will be made, as many radio phenomena are more clearly seen when their relation to the ether is understood. The electrical disturbance accompanying the transfer of radio messages really represents a wave motion in the ether very similar in principle to that of waves produced on water when its surface is disturbed. Unlike water waves, the ether waves

themselves do not affect any of the human senses, hence special devices must be used to make the signals intelligible. In all cases apparatus of suitable design must be used to produce and control the wave motion. The discussion of many types of equipment which enable the production and reception of electrical disturbances in the ether will be presented in succeeding Sections. In this discussion the description and use of many individual devices essential to this work will be given.

DEFINITION OF TERMS

3. A train of simple sine waves such as might be produced by an alternator is represented in Fig. 1. The straight line *a b* is known as the *axis,* as the waves are constructed with reference to it. A *cycle,* which has been defined as one complete set of positive and negative values, would be represented by the portion of the curve between *a* and *c, d* and *e,* or any other corresponding points. The *frequency,* as defined, is the number of cycles per second. Thus, if it required 1 second to complete 4 cycles, the wave-train would be said to have a

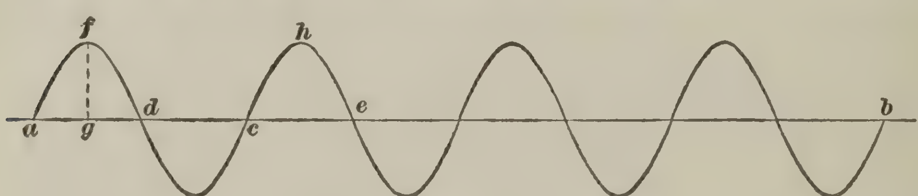


Fig. 1

frequency of 4 cycles. Similarly, if there were 1,000 cycles completed in 1 second, that wave-train would have a frequency of 1,000 cycles. The maximum height of a wave is usually called its *amplitude,* and would be represented by the distance *f g,* Fig. 1. The portion of a wave above the axis, as that between *a* and *d,* is called the *crest;* while that below the axis, as from *d* to *c,* is known as the *trough.* The length of a wave is the distance between the highest point of a crest to the highest point of the adjacent crest and is represented by the distance *f* to *h,* Fig. 1. The length of a wave takes in 1 cycle of changes.

AUDIO AND RADIO FREQUENCIES

4. Sound may be defined as the sensation produced through the organs of hearing or as the physical cause of this sensation, namely, the waves through an elastic body, especially through the atmosphere. According to the latter definition, sound is transmitted by a train of waves through the air from the object setting up the wave motion to the ear. Wave-trains having frequencies from 200 to 10,000 cycles are capable of affecting the human ear, and producing the sensation of sound.

Some persons cannot distinguish sounds over this wide range, while others can hear over a much larger range, but such frequencies are usually termed audible. This gives rise to the statement that *audio frequencies* are those between 200 and 10,000 cycles. As the average frequency in speaking is near 1,000 cycles, that value is taken as a basis in the design of apparatus to be used in the transmission of speech. Frequencies above 10,000 cycles are called *radio frequencies,* as they are commonly used in radio communication. The radio frequencies in common use vary over a considerable range but are usually comparatively high.

5. In the case of the water analogy, the waves travel along the surface of the water very slowly; but the electrical waves coming from a radio sending station travel through the ether very fast; namely, at the approximate rate of 186,000 miles in 1 second. The length of a wave on water may be between a fractional part of an inch and several feet. The length of waves commonly used in radio practice varies between 150 and 20,000 meters (492 and 65,600 feet). These wave-lengths correspond with frequencies of 2,000,000 and 15,000 cycles respectively. Waves shorter and longer than the limits given here are in occasional use, but the above represents the common practice.

6. It may be readily observed that dropping a relatively large stone into water will produce a much larger wave disturbance than will a small stone, other things being equal. Just

as the amplitude of the carrier wave is increased, so also is the energy received at any point much increased, a fact which will be evidenced by the violent up-and-down motions of a block of wood on the surface. This action is in general true also of radio signals, in that, with an increase in the amount of energy sent out, a corresponding increase in the strength of the received signals will be observed.

DECREASE OF AMPLITUDE WITH DISTANCE

7. The waves established in the manner already mentioned will be propagated in constantly expanding circles from the point of disturbance. The amplitude of the waves will decrease rather rapidly on account of the rapid increase in the length of the wave front; the length of the wave front corresponding to the circumference of the surface disturbance. This is a very important consideration and illustrates plainly the very large reduction in energy which may be received at any point, as the distance from the source is increased. The emitted waves in radio are sent out in practically all directions, and consequently suffer an even greater reduction in amplitude with distance than do the water waves.

ANTENNA SYSTEMS

RELATION OF ANTENNA TO WAVES

THEORY OF RADIATION FROM AN ANTENNA

8. Several theories have been advanced, each tending to explain the method by which electrical energy is transferred from the antenna to the surrounding ether. The phenomenon may be well expressed in the following manner:

Electrostatic and electromagnetic fields are established around electrical conductors when current is passing through them. When the current is alternating, the fields are constantly being established and removed in accordance with the current variations. The strength of the fields depends to a

large extent on the strength of the current producing the electrical stresses in the ether. When the current is decreased from a maximum to a minimum value, the stored-up energy is returned to the conductor except for a certain portion known as the radiation loss, which passes off into space. In radio practice this is not a loss in the true sense of the word, as this energy is that which is actually utilized in the transmission of signals. It has been found that there is not a large amount of energy given off by radiation, except when the frequency of the alternating current is high, say above 10,000 cycles, and that the radiation is increased very appreciably with an increase in the frequency. In radio practice frequencies below 15,000 cycles are seldom used, as the lower frequencies give poorer results. It should be understood that this represents the frequency of the current in the radiating conductor, or antenna, in this case. This explains the necessity for using high-frequency waves to establish satisfactory radio communication. All the electrical energy is not radiated at any frequency, but part of it returns to the conductor.

FEATURES AFFECTING OUTPUT

9. The current in the conductor is directly controlled by the input source, and is also affected to some extent by the ohmic resistance of the conductor itself. This then affects the radiated energy, which may be said to be a certain part of the energy in the antenna. Numerous experiments have proved that the presence of buildings, poles, and vegetation in the proximity of a radiating conductor may decrease the useful energy to an appreciable extent by absorbing a large part of the energy liberated at the conductor.

The electrical disturbances radiate out through the ether in all directions. Because of the properties of the earth, the waves are not present in it to any great depth. The surface of the earth, however, acts as a conducting path and very probably assists in causing the radiated waves to follow the general contour of the earth's surface. Transmission is usually much better over the ocean or other large bodies of water than over

dry and sandy soils, no doubt because of the better conducting properties of the water, and to the absence of objects which would absorb a considerable part of the passing energy.

10. It has been found that the distance over which radio communication may be satisfactorily maintained is much greater during the hours of night than it is during the daylight hours. There has thus far been no explanation of this phenomenon that has met with general acceptance.

11. A conductor placed in the path of the advancing electrical disturbances will have electromotive forces induced in it when cut by the waves. The energy received at any point will necessarily be much less than that sent out, but will possess all the essential characteristics of the original wave. By employing devices, properly arranged, the signals may be made intelligible to the receiving operator.

RADIATOR AND RECEIVER OF WAVES

PURPOSE OF ANTENNA

12. An **antenna** is the conducting system used in radio practice to radiate and absorb useful electrical disturbances in the ether. The antenna, or *aerial,* as it is sometimes called, may consist of a single vertical wire, or it may comprise an extensive wire network. In any case the purpose of the aerial is to provide a good means by which the electrical energy may be radiated into the ether at one place and received or taken from the ether at another. The amount of radiated energy varies with the type of antenna, being much larger with some designs than with others, even when the source of energy is the same in both cases. Similarly, the amount of energy received at any point will depend to a large extent upon the type of receiving network.

TYPES AND FEATURES OF ANTENNAS

13. Simple Vertical-Wire Type.—The simplest form of antenna, which was also an early style, is the *vertical-wire type* which consists of a single wire mounted in a vertical position, as shown in Fig. 2. The wire is usually supported by a pole or tower. Connection to the receiving device or set is made at some point, as *a*, for convenience located near the lower end of the wire. The current which is picked up by the antenna is then carried to the receiving set. A lead between the set and earth serves to make a ground connection for the system, as at *b*.

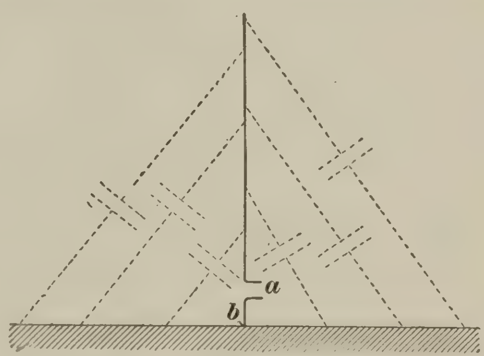


FIG. 2

The vertical-wire aerial has the advantage over some other types in that it will send electrical waves in every direction with equal strength. It is also able to receive disturbances from any direction with equal facility, which is in some cases a very desirable feature. This type of antenna is not commonly used because of the fact that a very high vertical supporting structure is necessary. It has been found that other less expensive types will give very satisfactory results, and in some cases even more desirable operating conditions.

14. The dotted lines in Fig. 2 represent the capacity of the antenna or the condenser effect between the wire and ground. The condenser action would perhaps be more clear were the

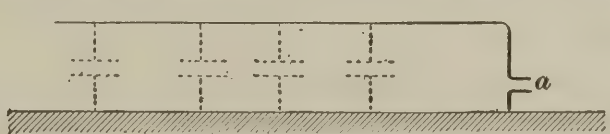


FIG. 3

conductor close to the ground as represented in Fig. 3. The two conductors, the antenna and the ground, with a dielectric (air) between them and with an electromotive force impressed

at *a,* will act as the plates of a condenser. This illustrates the point that there is really a closed circuit through which the antenna current is rapidly reversing, the circuit being completed through the large condenser formed by the antenna, the air, and the ground. As the capacity depends to some extent upon the effective area of the plates, one of which is actually the antenna and the other the ground, it is usual to connect two or even more wires in parallel. The same result is accomplished to some extent by increasing the length of the single wire.

15. Ground Connections.—The dimensions of the aerial may be enlarged to increase the capacity of the antenna circuit, but another way of improving the condenser effect is by providing a large conducting surface at the ground either below or above the surface of the earth. When the soil is dry, sandy, or rocky, it will not furnish a good conducting surface for large stations, even though the antenna is grounded well below the surface. To secure a good ground connection it is necessary to install an elaborate network of wires and plates either below or above the surface of the earth to correspond with the horizontal aerial.

When the network is placed below the surface of the earth, it is called a *conductive ground,* and when it is placed above the surface and insulated from the earth, it is called a *counterpoise.* The condenser effect is formed between the antenna and the lower conducting network, the latter having approximately the same surface area as the aerial.

16. The practice of making a connection to a metal pipe driven into the ground or even to a water pipe, is an exceedingly poor method of forming a ground connection. Unless a very low resistance path is provided at this point, considerable energy will be used up in the passage of the high-frequency currents through this part of the circuit. No doubt many of the troubles in low-power radio stations, attributed to other causes, are directly due to poor or inadequate ground connections. Well soldered joints, which are afterwards thoroughly cleaned of all soldering flux, are much to be preferred

in any part of an electric circuit to those made with poorly fitted clamps or twisted joints under which dirt or rust may accumulate.

17. Inverted L-Type Antenna.—The inverted L-type antenna is one in which the upper part of the conductor is placed in an approximately horizontal position, and the general appearance is that of an inverted L as shown in Fig. 4. A descriptive name which is sometimes used is the *flat-top antenna*. The point of contact of the instruments is at *a*. This type of construction is not exceptionally costly and is the form most frequently used in land stations. The length of the vertical and horizontal sections is often made approximately equal. In some special cases it is not possible to make the horizontal section very long, in which case the height is the greater dimension. Some stations have been built in which the horizontal length was a few thousand feet. In such cases it is impractical to make the vertical height as large as that; in fact, it is seldom made more than 200 or 300 feet, except in long-range stations.

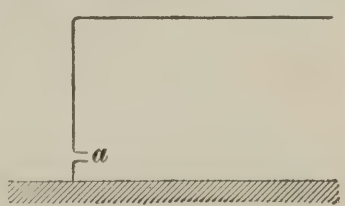


FIG. 4

18. Directional Features.—An antenna is directional when it will receive and send signals better in some directions than it will in other directions. The inverted L-type aerial is directional to some extent, in the direction opposite to its free end. This would mean that the aerial shown in Fig. 4 is capable of sending and receiving signals much more satisfactorily between other stations located directly in line with it and to the left, than with stations located in other directions from it. Communication with stations located to the right and in line with the station in Fig. 4 will be, in general, poorer than between stations located to one side. Long-distance communication is preferably carried on between high-power stations which are directional toward each other. In this manner signals are exchanged with the most economical use of the radiated energy, and the interference is also at a minimum.

19. The T-Type Antenna.—The T-type antenna is quite common on ship stations. As shown in Fig. 5, the general shape is that of the capital letter T. This type is particularly well adapted for use on vessels. The antenna may be supported between masts at the ends of the ship, and the *lead-in* to the set may be connected near the center of the wires and pass down to the operator's cabin, located at *a*. This type of antenna is equally directional along the directions of its horizontal part, or, in the case illustrated, to the right and left.

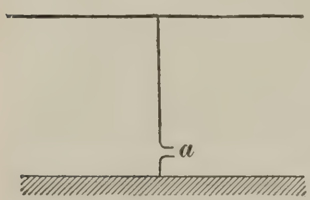


FIG. 5

20. Construction Features.—The descriptive name of flat-top antenna is sometimes applied to both the inverted L- and T-types, as the major part is usually horizontal. The number of wires does not often exceed six, although ten and twelve are sometimes used in large stations. The wires may be spaced from 2 to 4 feet or even farther apart, depending to some extent upon construction features. The several wires may be connected and fastened to one large lead-in wire, or they may all be extended to the receiving set. The individual wires may or may not be connected at the free end, no decided difference being observed between the two methods.

21. The wires are kept a suitable distance apart by a rigid mounting on supports called *spreaders,* which are commonly made of wood. Insulators are often placed between the ends of the wires and the spreaders supporting them. The spreaders, in turn, are supported on masts which elevate them to the proper height. Connection between the spreader and the mast should be made by means of good insulators; the type shown in Fig. 6 is very good for that purpose. As their prime purpose is to prevent the leakage of antenna current to the ground, they must be of ample dimensions to meet the given operating conditions. The mast may be of any suitable construction of ample strength to support the maximum load which

FIG. 6

may come upon it. In localities subject to sleet storms this load may be quite large. Wood is often used for masts of the smaller sizes, but iron- and steel-tower construction is preferable and more economical in the larger stations. When metal towers are used they should be insulated from ground at their bases. In any case suitable guying should be provided to enable the mast to withstand high winds and other atmospheric disturbances. Insulators should be placed at intervals in the guy wires to prevent the loss of energy through leakage.

22. The mechanical strength of an aerial will depend to a large extent upon the size of wire and the material of which

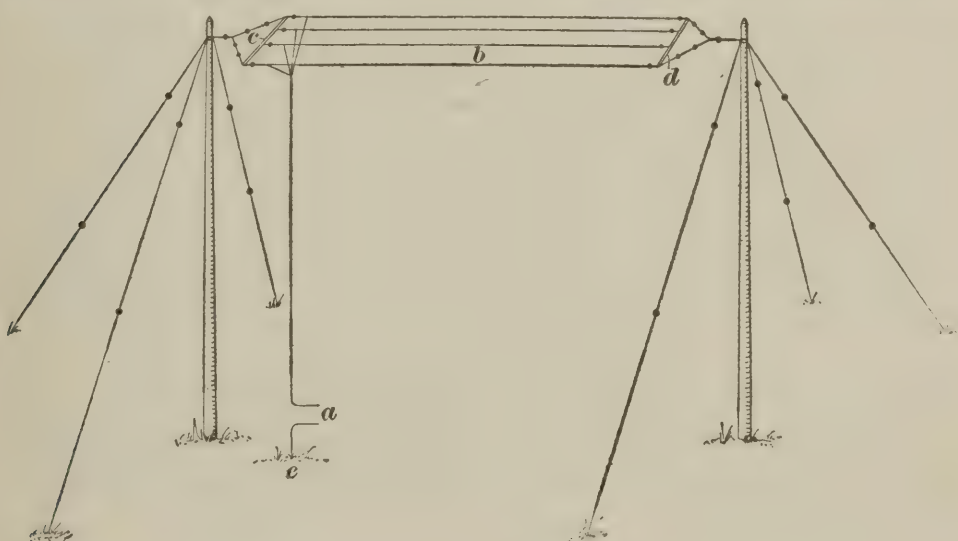


FIG. 7

it is made. If the aerial is long and supported at the ends only, it will be necessary to use a rather large wire. Number 14 Brown & Sharpe gauge is a good size to use in most stations operating on the shorter wave lengths.

No apparent advantage is gained by using insulated wire for the antenna; in fact, the added weight caused thereby is undesirable. The presence of trees or other objects close enough to require such insulation, will seriously interfere with the proper functioning of the aerial.

Bronze wire, because of its strength when placed under a heavy pull, and its rust-resisting qualities, is in common use. Copper wire is not so well adapted to this use, as it will not

stand a very heavy pull. It is satisfactory as a lead-in wire, however, and is often used in the counterpoise or ground system when installed either above or under ground.

23. Detailed Arrangement Features.—Some of the features entering into the detailed arrangement of an antenna are indicated in Fig. 7. This one is of the inverted **L**-type, with a connection to the receiving apparatus provided at *a*. The four wires comprising the antenna proper are shown at *b*. The insulators in the proper locations are represented by the small solid circles. When a wooden mast is used, it is not considered necessary to use additional insulation between its base and ground, as the pole itself is a fairly good insulator. The spreaders shown at *c* and *d* serve to keep the wires separated the required distance. The guy wires on the masts assist in resisting side strains and the pull of the aerial. The lead-in wire connects to the ground network at point *e*.

The general appearance of the **T**-type antenna is similar to the preceding type. The lead-in wire on the **T**-type would be connected at the mid-point of the aerial wires rather than at one end. In case the distance between the end supports of the **T**-type antenna is very great, a third support may be used at the center, and the lead-in taken from that point. This would still be a **T**-type antenna as far as its radio characteristics are concerned.

24. The V-Type Antenna.—The two horizontal parts of the aerial may be brought around so that the system has the general appearance of a large letter **V** when viewed from above or below. This type is known as a **V**-type antenna. This aerial is directional toward the crotch of the **V**, or toward the end at which the lead-in is connected. Three supporting poles or towers would, of course, be necessary with an antenna of this type.

25. Umbrella-Type Antenna.—Fig. 8 represents the general arrangement of the *umbrella-type antenna*. This antenna gets its name from the fact that the wires resemble in a general way the arrangement of the ribs of an umbrella or

the spokes of a wheel. Only two wires are shown opposite each other, but less than six are seldom used, and eight or ten is the more common number. The antenna wires are insulated from the mast and ground by insulators, as indicated by the small solid circles. The aerial wires in this type of construction act as sections of the guy wires, and adequately support the mast. This type of construction adapts itself to portable stations, and is used in many cases where a temporary construction is required. The receiving apparatus may be connected at *a* to the lead-in wire, which also connects the antenna wires together near the top. This type of antenna is not directional, as communication may be established in any direction with equal range.

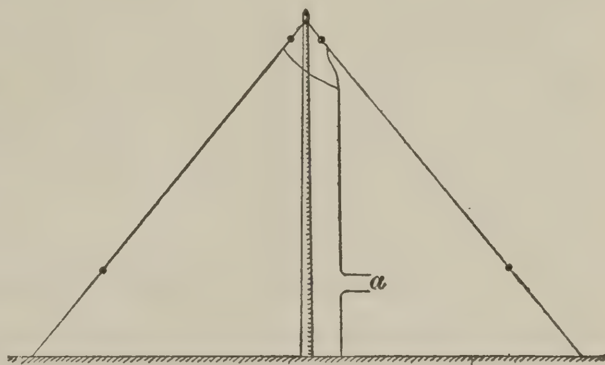


FIG. 8

26. Antennas resembling closely in general shape the one shown in Fig. 8 have been used on submarines and other rather short boats. The reason for using this type of construction is largely one of support, as no tall masts are available at the ends of the vessel to which the aerial wires may be attached. A lead from the inside to the metal hull of the boat makes an excellent ground connection.

27. Coil Antenna.—The *coil-type antenna* consists of one or more turns of wire with the receiving apparatus connected directly in the circuit. Fig. 9 represents a coil antenna of two turns, with provision made at *a* for connection to the receiving set. One to twenty or even more turns may be used in the coil and they may be wound quite closely together or with relatively large spacing between the adjacent turns. The coil antenna for convenience is usually

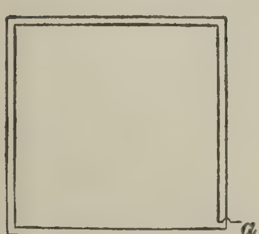


FIG. 9

wound on a square wooden framework from 3 to 10 feet on a side. Coils whose dimensions were outside these narrow limits have been successfully used for special purposes. Communication is generally better with the larger sizes, as the signals are likely to be very feeble when small coils are used. The small dimensions of this type of antenna make it readily portable, and this type is often used in outfits which are frequently moved.

28. Directional Properties of Coil Antennas.—The coil-type antenna is highly directional in a direction corresponding to the plane of the loop, that is, to the right and left when in the position represented in Fig. 9. The received signals will be at their maximum strength when either edge of the loop is pointing directly toward the oncoming wave, and at their minimum, or practically zero, when the plane of the loop is at right angles to the direction of travel of the approaching wave.

When the plane of the loop is in line with the approaching waves, one vertical side of the loop will be reached by a wave before the opposite side of the loop is affected by that wave. The electromotive forces thus set up in the sides of the loop do not arrive at their maximum and minimum values at the same moment. The differences in the instantaneous voltages establish an alternating flow of electricity in the loop. When the plane of the loop is at right angles to the approaching wave, the electromotive forces in the sides of the loop oppose and neutralize each other throughout the cycle because the sides of the loop are affected by a wave at the same instant. Radio waves of the shorter wave-lengths apparently travel in very straight paths. Measurements of the signals from stations using the longer wave-lengths, as for instance those above 10,000 meters, have disclosed the fact that their waves do not necessarily follow straight lines. A variation of 10 to 20 degrees, or even more, has been noted, and the deviation is by no means fixed or constant. The cause of this apparent drift has not been satisfactorily explained.

Since radio waves of the shorter wave-lengths travel in a

straight path, stations only a few miles apart may be located by this method with great accuracy. The antenna is mounted so it may be swung in a vertical plane, and rotated until the signals are at their maximum or minimum value. In some cases greater accuracy is obtained when the signals are the strongest, that is, with the coil in line with the sending station; in others a greater degree of accuracy is obtained by moving the coil to such a position that the received signal is at its minimum strength, or fades out. If, where a maximum is found, the coil be turned one-half revolution, or 180°, another maximum will be obtained, and this maximum will be exactly like the first. It is, therefore, possible to get the line of direction of a sending station, but it is impossible by this means to tell in which direction along this line the station lies.

29. So reliable is this directional property on the shorter wave-lengths that coil antennas are used in the guiding of ships and airplanes, the steering being accomplished with reference to some fixed sending station or stations. This use has given rise to the name of *radio compass,* a term which is frequently applied. The radio compass, however, merely gives the line of direction of the sending station, and the real direction of the transmitter must be determined by the judgment of the operator.

FIG. 10

30. Location of Sending Stations by the Radio Compass.—Two or more radio compass stations may be used to obtain the location of a sending station with a very close degree of accuracy. The United States Government has established several such stations along the coast particularly for the use of ships during weather of low visibility.

A ship located at *a,* Fig. 10, requests its bearings from the compass stations *b* and *c,* and starts sending signals. The operator at station *b* turns his coil antenna until he obtains

the direction of the line *a d*, and sends the reading to the ship operator, usually so many degrees from the geographic north in a clockwise direction. As this station is located on a peninsula, the operator at *b* is unable to tell in which direction the ship lies; that is, whether the ship is in direction *a* or *d* from him. The operator on the ship, knowing the position of station *b*, would locate the line *a d* on a map, or, if he knew his position with respect to *b*, he would need to draw in the lower part of the line only. As a ship station could not lie on the land side of station *c*, the exact direction of the ship from this station may be obtained by the operator at *c*. With the data sent by the operators at *b* and *c*, the operator on the ship at *a* is able to determine his exact location from the intersection of the lines *a d* and *a c*.

31. Wire Used in Coil Antennas.—The conductor used in a coil antenna is usually quite small, number 20 Brown & Sharpe gauge cotton-covered wire being quite frequently used. The cotton covering provides insulation between the adjacent turns of the wire and also between the wires and the wooden framework on which they are ordinarily wound. No other insulation is considered necessary, as the voltage is not high. The receiving set is connected directly in series with the circuit of the coil, hence no ground connection or counterpoise is required. The coil-type antenna has not come into use as an aerial for the sending of radio signals, as the amount of energy radiated is very small when compared to some of the other types. When the dimensions of the coil-type antenna approach those of the open-wire type, its characteristics more nearly approach those of the open-wire type.

32. Underground Antenna.—Many successful experiments have been made in which the receiving antenna system was placed under ground or under water. These tests seem to prove that a considerable electric wave disturbance passes through the surface of the earth or water adjacent to the free air space through which the ether disturbances readily pass. The antenna is usually stretched out on each side of the station although, in some cases, good results are obtained when two

long pieces of conductor are coiled and the two coils placed a short distance apart in the earth or in water. The wires of the coils are insulated and waterproofed. The distant ends of the coils are left free, or open.

In the straight antennas sometimes the distant ends are grounded and sometimes the whole length of the conductors is insulated. In the latter case both for coils and straight wires the insulated conductor acts as one plate of a condenser and the earth as the other plate. At any given instant radio waves cause differences in the electromotive forces at different points on the earth's surface. When the conductors are insulated, alternating current is established in the receiving set through condenser action, and when the distant ends of the conductors are grounded, the current is established through condenser action as well as by conductance. The underground type of antenna has not met with much success when used in transmitting signals. Good results with reference to the receiving qualities of this antenna have been recorded even in long-distance work.

WAVE-LENGTH OF AN ANTENNA

33. The length of the radiated wave depends upon many features of design, construction, and location of the antenna. Among the specific factors controlling or affecting the wave-length may be mentioned: vertical and horizontal dimensions of antenna, type of construction, length and ohmic resistance of lead-in wire, length and ohmic resistance of ground wire, effectiveness of ground connection, number of wires in the aerial and their spacing, the proximity of absorbing mediums, and the effectiveness of the insulation of the conductors from their supports. Comparatively simple devices for measuring the wave-length are on the market, and represent the only reliable means for determining the wave-length of a particular radiated wave. By their use the so-called natural wave-length of an antenna may be determined. These devices will be described in a succeeding Section.

34. As an antenna will radiate a larger amount of the energy supplied to it when its natural wave-length is near that

of the transmitted wave, it becomes desirable that the wave-length be known. This is rather hard to predetermine accurately when building a particular station. Methods will be explained in a succeeding Section, by which small changes in the natural wave-length may be accomplished.

The wave-length is not such an important factor in the design of an antenna used only for receiving radio messages. In case the antenna is used for both sending and receiving, it is designed primarily for the sending qualities as these are usually the more important. It will then usually be suitable for receiving purposes, especially for working with other stations operating on nearly the same wave-length. Signals may be received on very small antenna systems, but they are apt to be quite feeble. In general, a large aerial will bring in much stronger signals than a small one, and apparently with no loss in accuracy or readableness.

STATIC

35. Static disturbances, noticeable in radio receiving apparatus, are apparently caused by static electricity in the atmosphere. These disturbances are occasionally called *atmospherics,* or *strays,* and in some cases are very troublesome. No really satisfactory explanation of their origin has been offered, and no plan for eliminating these disturbances completely has been generally adopted. In some cases a charge of electricity appears to collect on the antenna which discharges all at once through the receiving apparatus, and in other cases a continuous roaring or rattling sound is heard.

The disturbance is, in general, worse in warm weather than in cold weather in any one locality, and becomes more serious at all times the nearer the station is to the equator. Aurora borealis displays also cause disturbances which it is very difficult to separate from the signals coming in from the antenna. A coil-type aerial is perhaps as free from such interference as any of the various types previously mentioned, partly due to the fact that ordinarily it is not grounded. The underground antenna is not affected by static as much as some other types, but this advantage is accompanied by a loss in signal strength.

OSCILLATION TRANSFORMERS

TRANSMITTING TRANSFORMERS

36. Purpose of Transformers.—The high-frequency alternating currents, or oscillations, as they are sometimes called, are usually produced in circuits especially arranged for this purpose. These oscillating currents are then transferred to the antenna for sending by means of an oscillation transformer. Ordinary iron-core transformers do not permit high-frequency currents to pass through them, hence the necessity for air-core transformers with proper characteristics. Devices serving the same purpose, and in almost a similar manner, are used in radio receiving work. In this case they are commonly called *receiving transformers,* although names such as *tuners* and *couplers* are less frequently applied.

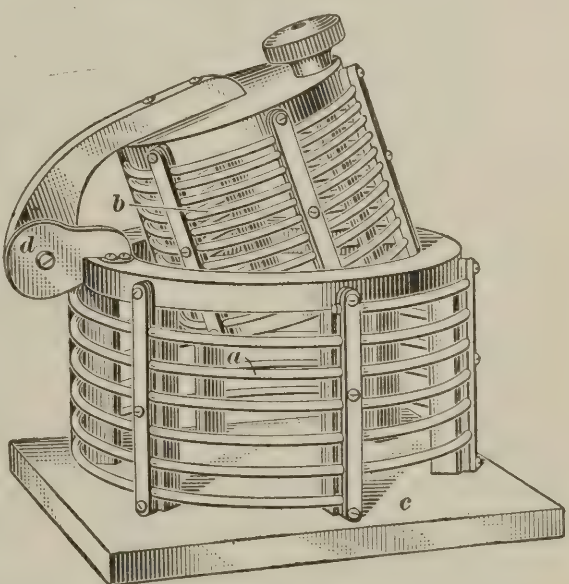


FIG. 11

37. Helical-Coil Transformers.—In Fig. 11 is shown a common type of oscillation transformer which is used in many medium-power stations. The larger helical winding *a* is customarily the primary, or the one which receives the energy from the generating devices, although the coils may be used interchangeably. An alternating current in coil *a* sets up lines of force which interlink the windings of the secondary coil *b* and establish high-frequency currents within it. The secondary, which is also a helical winding, is con-

nected in series with the antenna system, hence the energy of the oscillating current is transferred to the radiating system, and sent out into space.

The whole device is mounted on an insulating base *c*. Insulating posts serve to support the windings and to keep the turns of wire in their proper relative positions. The windings of the transformer shown are made of heavy copper wire. Adjustment is provided by means of a hinge joint *d* which allows the secondary coil to be moved over a considerable range of positions with respect to the primary. When the coil *b* is moved away from coil *a* there will be fewer lines of force cutting it, hence the energy transmitted to the secondary will be smaller.

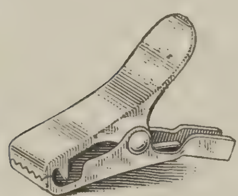


Fig. 12

In order to change the number and the positions of the turns of the primary and secondary coils that are active, clips similar to the one shown in Fig. 12 are attached to the ends of the wires leading to the transformer. These connectors are clipped on to the turns at the proper points to produce the electrical effects desired.

38. To reduce the losses due to skin effect, it is desirable to use flat strips of copper or copper ribbon instead of round copper wire. The oscillation transformer shown in Fig. 13 has both its primary winding *a* and secondary winding *b* made of flat copper strips. Unlike the previous type, the secondary winding is larger in diameter than the stationary primary coil. As in the preceding case, the secondary is hinged at one edge. The

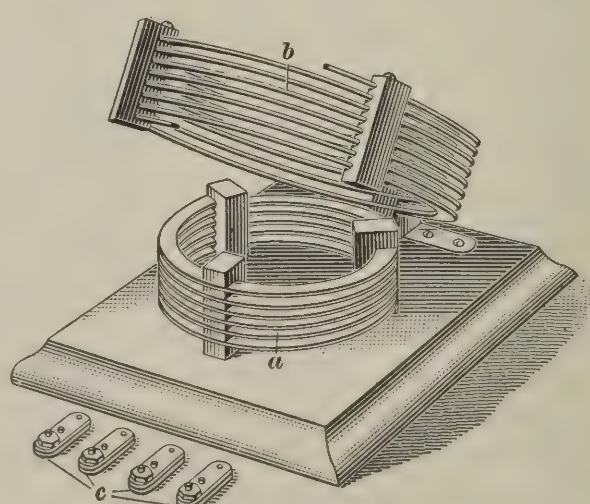


Fig. 13

principle of operation is not changed by this different arrangement of the coils. The small clips *c* enable the circuit wires to be connected to the windings at any desired points.

39. Flat Spiral-Coil Transformer.—Another type of construction is shown in Fig. 14, in which the two coils *a* and *b* are each wound in the shape of a flat spiral, which gives rise to the name of *flat spiral-coil transformer.* The conductors are flat copper strips which are set in grooves in radial insulating supports. Mounting blocks and a hinge arrangement *c* permit the coils to be placed in different relative positions. When they are near together practically all the lines of force estab-

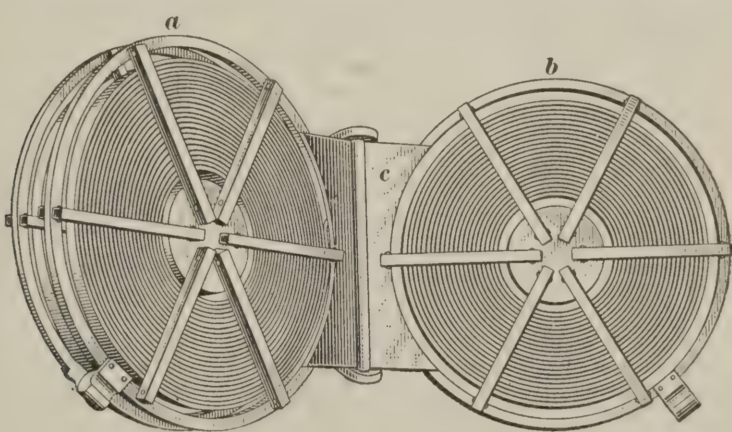


FIG. 14

lished by one coil will cut the other and a maximum of energy will be transmitted from one coil to the other.

As the coils are separated, the transferred energy will decrease considerably and when the coils are at right angles, very little energy will be transferred. As the coils are identical, either may be used as the primary and the other the secondary. Clips are provided for connecting to the conductors at any desired points. Quite accurate adjustments may be made between the two circuits including these coils by changing their relative positions. The flat-spiral coils are also known as *pancake coils.*

40. Instead of the coils being hinged, these flat coils may be mounted on a common axis along which they may be moved. The coils remain parallel during the complete range of adjust-

ments; the distance between the two coils determines the amount of energy transferred from one to the other. The principle of operation is nearly the same as in the preceding case, as the greater the distance between the coils the smaller will be the number of lines of force linking the secondary, and the smaller will be the energy transferred.

For the best operating conditions it is preferable to have the primary and secondary made up of separate coils. In some installations a single flat spiral, or helical type of coil serves both as the primary and secondary. Its action may be compared with that of an autotransformer. Clips are attached at the proper points on the coil to give the desired ratios of energy transformation.

COUPLING

41. Two circuits which have a common magnetic or electrostatic field or are linked together by such fields, are said to be *coupled*. Inductive coupling is obtained by using an oscillation transformer with two separate coils, one of which is connected in one of the two circuits, and the other connected in the other circuit. Two circuits are connected by *direct coupling*, also called *conductive coupling*, when a single coil is used, which is common to both of the circuits. These terms apply equally well to transformers used for sending and receiving radio signals.

42. There is one other type of coupling which is used to some extent and may be advantageously mentioned at this point. As stated above, two circuits may be coupled together by an electrostatic field. Thus when two circuits are connected together by a condenser which is common to both circuits they are said to be in *capacitive coupling*, or *capacity coupling*. The actual transfer of energy from one circuit to the other takes place through the condenser.

RECEIVING TRANSFORMERS

43. General Characteristics.—The amount of energy transferred and radiated from sending stations is quite large, a fact which necessitates the use of rather large windings in the oscillation transformer. The amount of energy handled by a receiving set is in all cases very small. For the transfer of this energy from the antenna circuit to the actual receiving devices it is common practice to use an oscillation transformer. As the energy is so minute, the windings are constructed of many turns of very fine wire. In most cases the wires are insulated by cotton or silk covering, although it is possible to wind them in such a way that an insulating air space will be left between adjacent turns.

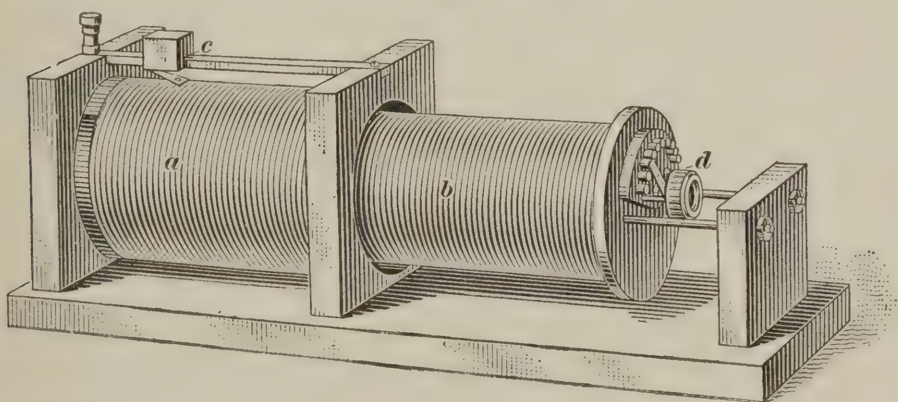


Fig. 15

44. Simple Receiving Transformers.—A quite simple receiving transformer, or tuning coil, as it is sometimes called, is shown in Fig. 15. The primary coil is shown at *a* and is connected directly in the antenna circuit. The secondary coil *b* is of a smaller diameter and may be moved into or out of coil *a* by sliding along stationary rods which support it. By this means the amount of coupling may be varied over a considerable range.

A slider *c* may be moved along coil *a*, and it makes contact with the individual turns of the wire. The slider makes electrical contact between the wire which it touches and the terminal on the rod on which the slider operates. Only those

turns of the primary coil which are connected between the wire with which the slider makes contact, and the end of the coil which is connected to the antenna circuit, carry the antenna current. The action of switch *d* is explained later.

45. Switches Used on Receiving Transformers. The action of the slider on the primary coil is illustrated clearly in Fig. 16. The coil *a* is shown diagrammatically, as is also the rod *b* carrying the slider *c*. If the antenna circuit is now connected to terminals *b* and *d*, only the portion *d e* of the entire length *d f* of coil *a* will carry the antenna current and be effective in establishing lines of force. A larger or smaller number of turns of the primary may be used by moving the slider to the right or left respectively.

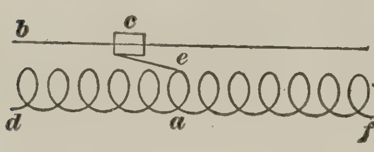


FIG. 16

46. A different type of switch arrangement is that used on coil *b* and shown at *d* in Fig. 15. Fig. 17 illustrates the connections for such a switch. The main coil is shown at *a* and the switch proper at *b*. Taps *1, 2, 3, 4,* and *5* are connected by suitable leads to such points on the coil that equal numbers of turns are included between adjacent contact points. The wire which carries the secondary current is that included between the point with which the switch point makes contact and the fixed terminal *c* that is connected to the receiving devices. In this case, the portion of coil *c d* between *c* and *e* is the part which actually carries the secondary current. The circuit is completed through the lead to switch point *3*, and then through the switch *b* to the other terminal of the receiving devices.

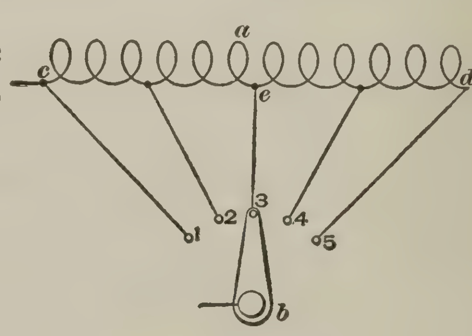


FIG. 17

The number of turns in which current is established may be increased or decreased by moving the switch to the right or left respectively. Every change of position of the switch connects or disconnects several

turns of wire, the number depending upon the total number of turns in the coil and the number of contact points.

47. The arrangement shown in Fig. 18 permits adjustments by individual turns over the complete range of the primary coil. Switch *a* makes contact with points between each of which are connected ten turns of wire. The adjustment of switch *b* is over points which are connected by leads to adjacent turns on a section of the coil *c*. Fig. 18 does not show ten turns between adjacent points of switch *a*, but assuming this condition, then the setting shown would be such that fifty-five turns would receive the antenna current. The current enters at switch *a*, passes through the portion of the coil connected between the switches, and out at switch *b*. For a preliminary rough setting switch *a* would be placed on a point near the desired value, and the final and more careful adjust-

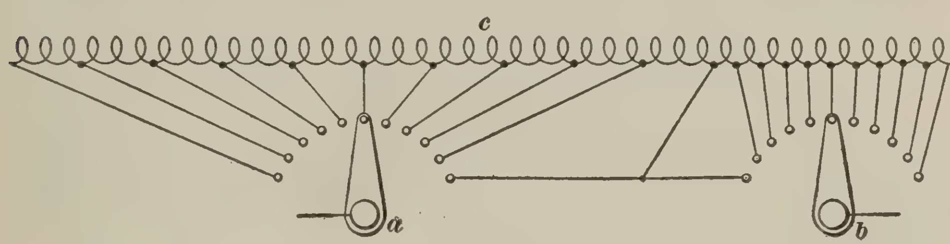


Fig. 18

ment would be made by changing switch *b* to the proper contact point.

Other switch arrangements for accomplishing the adjustment by single turns are possible and are in successful use. A careful inspection will usually reveal the method of operation. In some cases numbers are stamped near the switch points which refer to the number of turns of wire connected in the circuit when the switch is on that contact point. This arrangement is not used on the oscillation transformer previously described, but is employed on a type which will be discussed later on.

48. It is often desirable to use only one set of coils for all radio receiving work. This necessitates the use of rather long coils of wire for the complete range of variations desired. It has been found in practice that the turns of a coil which are

not used take considerable energy from the useful portion and thus prove a detriment to the receiving system. In case only a small portion of the coil is actually used and the coil is very large, the above consideration is very important. The means often taken to prevent this loss are represented in Fig. 19. The coil is divided up into three sections *a, b,* and *c,* and a switch *d* of regular design makes contact with several switch points, which are in turn connected to the coil by short leads. Switches *e* and *f* serve to connect the short coil sections in series when it is desired to use more than the one section.

If it is desired to use only a short length of coil, switches *e* and *f* are opened and the blade of switch *d* is placed on the proper point *1, 2,* or *3.* The coils *b* and *c* being totally disconnected from the circuit, have no effect on coil *a,* hence cannot

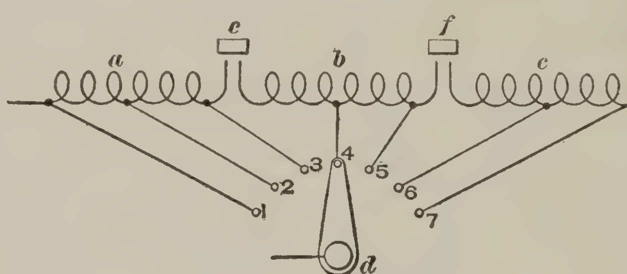


Fig. 19

produce any losses. If a larger coil is desired it is only necessary to close switch *e* and move the blade of switch *d* over to points *4* or *5.* When it is necessary to use all the turns of wire, switches *e* and *f* are closed and the blade of switch *b* is placed on point 7. The losses caused by turns which do not carry any current are often termed *end-turn* losses. A switch such as has just been described for sectionalizing a large coil, is called an end-turn switch.

49. Complete Type of Receiving Transformer. A receiving oscillation transformer combining several refinements of design, is shown in Fig. 20. The box *a* houses the primary coil, thereby affording considerable protection from reckless handling and other causes. The secondary coil *b* may be moved into or out of the primary on the sliders which both support and guide the movable coil. The double-switch

arrangement *c* permits adjustment of the number of primary turns by single steps, or turns, by the method which has already been described. These switches are connected to the two terminals at *d*, one of which provides a ground connection, the other one being for the attachment of the antenna lead-in.

Should a high voltage discharge come in on the aerial wires, it would readily pass across the short air gap between the terminals at *d* and discharge harmlessly to the ground, thus protecting the transformer. A simple switch *e* permits adjustment of the number of secondary turns actually connected in that portion of the circuit. Connection between the secondary coil *b* and the secondary terminals at *f* is made by means of

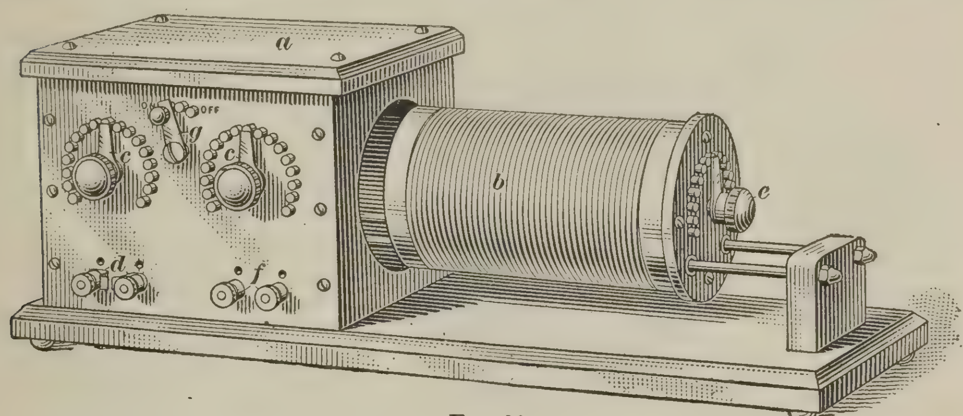


FIG. 20

flexible conductors. An end-turn switch *g* divides the primary into two sections, one of which may be disconnected when it is not required in order to minimize end-turn losses.

50. The large oscillation transformers, or tuning coils, used in radio receiving are usually of the types previously described. To increase the inductance, which as will be explained in a succeeding Section is sometimes desirable, the single-layer coil must be made very long. By using a shorter coil with several layers of winding, the inductance is very much increased over what it would be in a long single-layer coil of the same number of turns. The winding is also more compact and economical of space. However, the multi-layer coil has a higher distributed capacity between turns, which in short-wave work is particularly objectionable. Such coils must

be carefully designed and constructed, or they will not operate properly. A type of winding which reduces the distributed capacity over that of a solid multi-layer coil without seriously affecting the inductance will be described.

51. Honeycomb Coils.—A long piece of wire may be formed into a short coil by the type of winding indicated in Fig. 21. It will be noticed that there is considerable space between adjacent turns of wire and that the wires of one layer lie at an angle with those in the adjacent layer. The capacity effect of one wire upon those adjoining is thus reduced and it is entirely practicable to construct coils of this type with several layers of conductor. On account of the open type of construction, they are sometimes called *honeycomb-wound coils,* and are sold under several trade names. They are customarily furnished with leads from the ends of the winding, which starts at the center and is gradually built up to the desired thickness layer by layer. Leads may be taken off at intermediate points if it is desired to make adjustments in that manner.

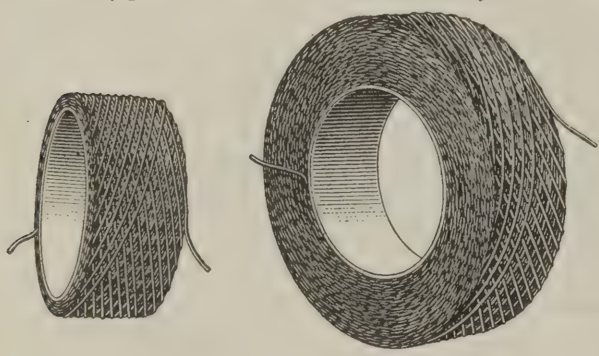


Fig. 21

Another arrangement for making adjustments is to mount two or more coils of different numbers of turns, but similar interior diameters, side by side. Each coil is provided with a plug switch mounted on its outer surface. By placing a metal plug in the switch, the coil may be cut into circuit. Any one of the set of coils may be made active depending on the number of turns that are required by the operating conditions. When fewer turns are desired, the use of a coil of smaller size is preferable to taking off leads at intermediate points of a larger coil.

52. These coils may be mounted in various ways so that the coupling between them may be changed. Because of their

construction, they cannot be placed one inside the other, but are placed side by side as in the case of the pancake coils. They may then be supported so that the angle and distance between the coils may be made variable, or the distance between them only may be variable, the coils still remaining parallel.

The coils are made of insulated wire, and the conductors are made either of solid or stranded copper wire. A paper or bakelite tube forms the center support and the whole is well shellacked, thereby forming a fairly rigid unit which is reasonably moisture-proof.

53. Variometer.—As has been stated, the usual purpose of changing the number of turns used in coils of receiving transformers is to change their inductance. Another method by which this may be accomplished consists in dividing the winding into two sections and then placing these sections in such relative positions that the inductance is changed.

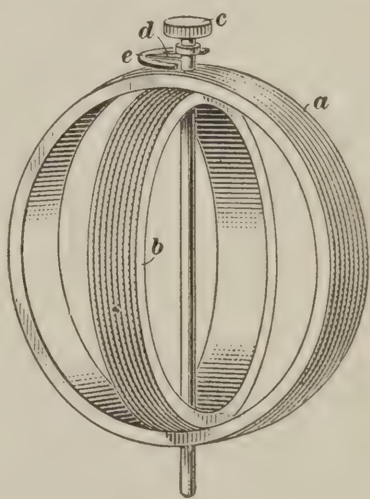


Fig. 22

In Fig. 22 is shown the operating principle of a device commonly called a *variometer,* for varying the inductance of a circuit. The outer coil *a* is usually stationary and the inner coil *b* is so mounted that it may be rotated within coil *a*. The knob *c* is on the end of a shaft that passes through both coils and supports the inner coil. The movable coil rotates when the shaft is turned, and the angle between the two coils is thus changed. A pointer *d* and scale *e* indicate the angular relation between the two coils.

54. As indicated in Fig. 22, the wire is wound on forms which are sections of the surfaces of spheres. In this manner the two coils may be of almost the same diameter and yet the inner coil may be freely rotated. A small section near the center of the winding surface cannot be wound with wire, as the supporting shaft passes through at this point. The num-

ber of turns of wire used will depend upon the design and the size of the winding space available. In actual practice the coils are often wound on short cylindrical tubes. In such a case, however, the diameter of the inner tube must be much smaller than that of the outer one in order to allow the movable coil to be rotated. In other cases the outer winding is placed on a cylindrical tube and the inner one is on a spherical surface.

55. The stationary and movable coils are connected in series and the variometer may be connected in the antenna circuit or the secondary circuit, depending on the results required. When the coils are in parallel positions and are connected so that electricity flows through them in the same direction, the lines of force which they establish act in the same direction and the coils have practically no effect on each other. In this position the inductance of the device is at its maximum, as the lines of force of both coils are added directly. When the inner coil is turned to some other position, its lines of force move also and do not act completely in unison with the flux set up by the outer coil, but at an angle with it. The effect of a portion of the total number of lines of force is thus lost and the inductance of the device is decreased. Continued rotation of the inner coil will decrease the inductance more and more until the position is reached in which the two coils are parallel and opposing each other. If then the two coils are equal, the inductance of the device will be nearly zero, as the lines of force of the two coils will tend to neutralize each other.

56. A distinct advantage of this type of construction is that a continuous variation of inductance may be made over the whole range of values obtainable with this device. When complicated switch arrangements are used, the inductance is usually variable by steps of one turn of the winding. As commonly used, the variometer is made in small sizes and is depended upon to give a small range of gradual inductance variation.

Devices somewhat similar in design and principle of operation are in use, particularly in small size receiving sets. In such cases the two coils of a variometer are usually connected in

separate circuits, and the action between them closely resembles that of the oscillation transformer.

57. Variation of the Coupling.—A method for varying continuously the coupling between two circuits is indicated in Figs. 23 and 24. Fig. 23 shows a simple oscillation transformer of helical coils closely coupled. Nearly all the lines of force of one coil interlink with the windings of the other. When one of the coils is moved to one side as shown by Fig. 24, many of the lines of force do not interlink and the coupling is considerably reduced. Intermediate settings give uniformly variable changes in the linking of the lines of force with the two coils. This method of variation is also applicable to the pancake type of coil. The above method of varying the coupling has not come into general use in the United States, although it has been successfully applied in other countries.

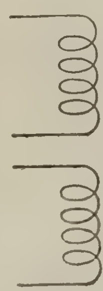


Fig. 23

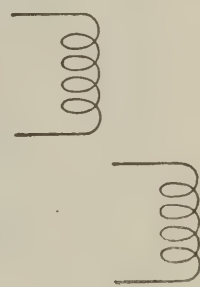


Fig. 24

AUDIO-FREQUENCY TRANSFORMERS

58. Air-Core Type.—The oscillation transformers which have been described are exclusively used for the transformation of radio-frequency electric waves and the primary is often connected directly in the antenna circuit. Fig. 25 shows an air-core transformer designed for the transfer of radio- and audio-frequency currents from one circuit to another in receiving apparatus. The winding is mounted on a supporting tube of insulating material and is constructed in layers. A covering *a* protects the coils to some extent and adds to their appearance. The end blocks *b* carry on their upper edges suitable terminals for the primary and secondary windings.

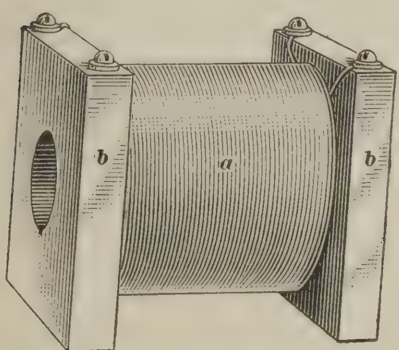


Fig. 25

59. Iron-Core Type.—More satisfactory results in transferring audio-frequency currents from one circuit to another in receiving apparatus are in most cases secured by using an iron-core transformer such as is illustrated in Fig. 26. The shell-type iron core *a* provides a good path for the magnetic flux which interlinks both windings. The primary coil *b* is wound next to the iron core, and the secondary coil *c* surrounds the primary. For some purposes the ratio of the number of primary turns to secondary turns is approximately one to three, although other ratios are often used. The coils are formed of many turns of very fine wire, and are connected to binding posts on the top of the transformer. Suitable markings distinguish the terminals of the two coils.

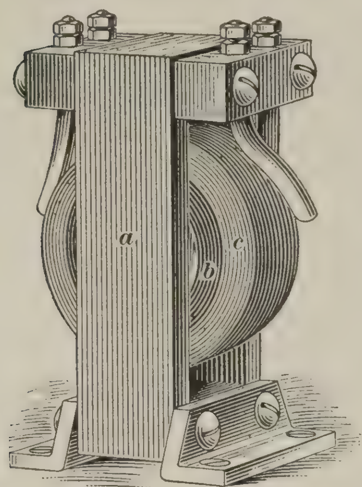


Fig. 26

SYMBOLS

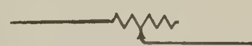
60. The symbols indicated in the accompanying table will be used as far as practical in the illustrations that refer to radio apparatus and circuits. A study of the symbols will aid in understanding the many connection diagrams shown in the Sections treating on this subject.

Conventional Symbols for Radio Devices

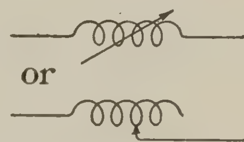
Crossed wires not joined 

Joined electrical conductors 

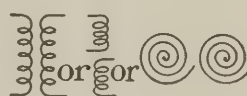
Resistance (not variable) 

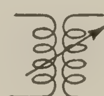
Variable resistance 

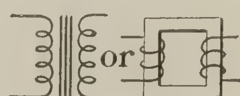
Fixed inductance 

Inductance, variable
or adjustable 

Inductance, iron core 

Coupled coils, air, or
oscillation transformer.
Also, mutual inductances 

Coupled coils, with
variable coupling 

Iron core or
power transformer 

Condenser, fixed 

Variable condenser 

Antenna 

Coil aerial 

Ground connection 

Ammeter 

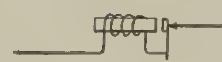
Crystal detector 

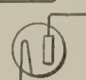
Telephone transmitter 

Telephone receiver 

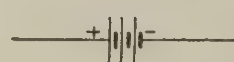
Spark gap 

Quenched gap 

Buzzer 

Electron tube, 2 element 

Electron tube, 3 element 

Battery 

Generator, direct current 

Alternator 

Arc, oscillating 

Enclosed fuse 

Signaling key 

Switches:

Single-pole single-throw 

Single-pole double-throw 

Double-pole single-throw 

Double-pole double-throw 

Reversing 

RADIO DEVICES
(PART 2)

CONDENSERS

GENERAL FEATURES

DEFINITION OF TERMS

1. An **electric condenser** is a device consisting of two conductors separated by an insulating medium. The name *condenser* comes from the fact that such a device has the ability to crowd, or store up, more electricity in the space separating the two rather large conducting surfaces than would be the case if the two conductors were widely separated.

2. An electric condenser is formed when any two conducting substances are separated by an insulating medium. For example, a suspended wire and the earth may form the conducting substances and the air between them would be the insulating material. The conducting substances are commonly called *plates,* as they are ordinarily made in the form of large flat surfaces when used in commercial condensers. The insulating medium is known as the *dielectric* of the condenser. In the above example, the suspended wire and the earth form the plates and the air forms the dielectric.

ACTION OF A CONDENSER

3. When an electromotive force is applied to the terminals of a condenser electricity flows into the condenser until the opposing, or counter electromotive, force of the condenser

equals the applied electromotive force. The condenser is said to be *charged* when it has received all the electricity which it will store up under existing conditions. In actual practice this condition is seldom reached, but the condenser is considered charged when it has received its rated amount of energy.

4. When an electromotive force is connected across the plates, electricity will apparently flow and be stored in the condenser. The action is somewhat analogous to that of a water-storage reservoir. Water may be pumped into an elevated tank under pressure and is then stored up until required. Such is, briefly, the condition of an electric condenser when electricity has been forced into it under electric pressure. It is not practical, however, to store electrical energy in this manner for a considerable length of time; in fact, the operation is more satisfactory the shorter the interval of time between the storing and withdrawing of the charge.

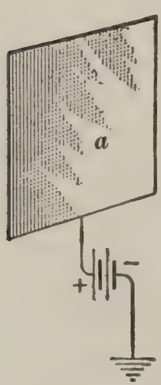


Fig. 1

In the case shown in Fig. 1, the condenser consists of the conducting plate *a* and the ground, the dielectric being the intervening air. The battery serves to produce a charge in the condenser. Electricity will flow into the plate *a* until the electromotive force between the plate and ground is the same as the battery voltage.

5. The first antenna systems used in radio telegraphy made use of a system very similar to that of Fig. 1. The battery was, of course, replaced by the transmitting or receiving apparatus and plate *a* was elevated. It is well to remember that any antenna in combination with the earth possesses capacity. The characteristics of condensers will thus be seen to apply to a considerable degree to antennas.

6. The exact changes taking place in a condenser when it receives a charge are of an electrical nature and not visible. If the plates form reasonably good conducting surfaces, the material of which they are constructed is rather unimportant.

The capacity of the condenser is directly affected, however, by the material of which the dielectric is made. While the condenser is being charged, the dielectric is subjected to an electrostatic stress which establishes an electrostatic strain in the dielectric. As soon as the electromotive force which produces the charge, is removed, the dielectric tends to regain its original condition and the electrostatic strain is relieved.

The condenser shown in Fig. 2 serves to illustrate the principle involved. The two plates *a* and *b* are quite close together and the intervening air forms the dielectric.

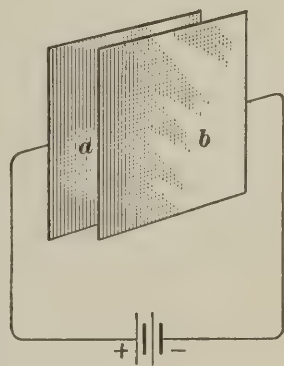


FIG. 2

As soon as the circuit is closed through the battery, there will be a flow of electricity into the condenser. The flow will be at maximum value upon closing the circuit and then will rapidly fall off, so that after a small fraction of a second, the flow will practically have ceased and the condenser will be charged. Plate *a* will have a positive charge and plate *b* a negative charge.

CLASSIFICATION

7. Condensers, as usually constructed, may be divided into two general classes—variable and fixed condensers. In a variable condenser the relative position of the plates may be changed, thus affecting the capacity of the condenser. In a fixed condenser, the plates are held in the same relative position to each other. Practically all variable condensers are made with rather thick self-supporting plates, and either a gaseous or liquid dielectric. Fixed condensers, or those of constant capacity, may be made in a similar manner, but are more often made of very thin sheets of conductor interspersed between layers of solid dielectric material.

CONSTRUCTION

8. Variable Condensers.—The plates of practically all variable condensers are made of aluminum, for the reason that aluminum is light, easily workable, rigid, and a good conductor. Other metals may be used for the plates, but the use of aluminum has become nearly universal in this field, because of its freedom from corrosion and other features which cause the capacity of the condenser to vary from time to time.

The principle of a variable condenser will be explained with reference to Fig. 3. The aluminum plates are separated by the air as a dielectric. The plates at *a* are rigidly mounted by

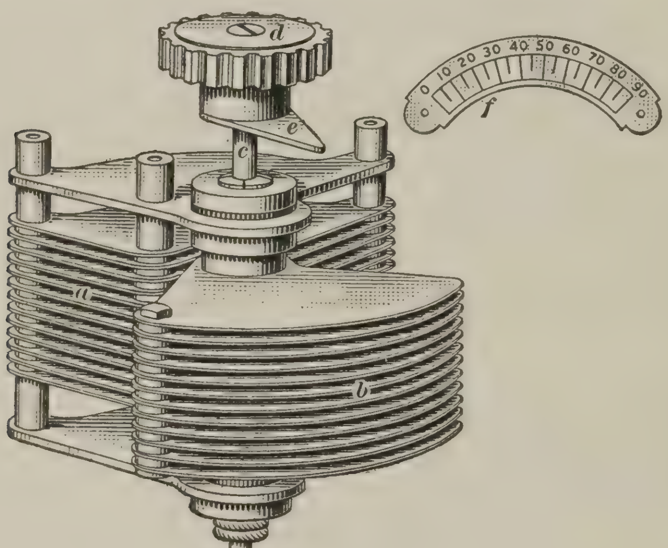


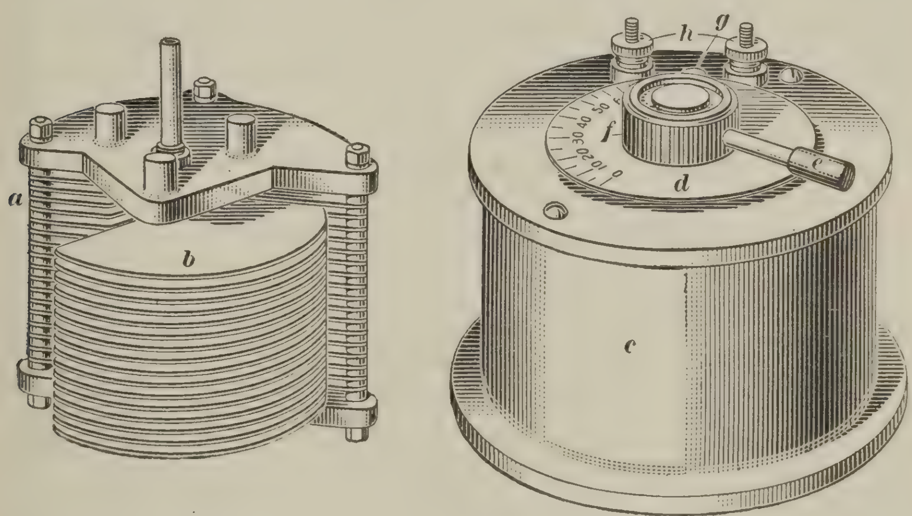
FIG. 3

means of corner posts and separated at the proper distance by washers. The movable plates *b* are fastened securely with respect to each other, and carried by the shaft *c* which extends through them. The spacing is the same as for the stationary plates. Their position with reference to the stationary plates is such that when the movable plates are rotated on their axis, the plates will enter midway between the stationary plates.

In this condenser, the plates are quarter sections of a complete disk, although as usually constructed, they are semicircular. The capacity of the condenser is zero when the plates

are in the relative position shown. The capacity of the condenser is increased as the movable plates enter between the stationary plates and becomes a maximum when the surfaces of plates *b* are completely covered by plates *a*. The movable plates are insulated from the stationary plates; therefore, when an electromotive force is applied, an electrostatic strain is established in the dielectric and the condenser becomes charged.

9. The condenser unit is ordinarily mounted inside a suitable protecting case. The shaft *c*, Fig. 3, is then extended through the cover and carries at its upper end a knob *d*. The knob being secured to the shaft permits the movable plates to



(a) (b)
FIG. 4

be rotated. A pointer *e* and scale *f* are usually provided. The scale is divided from 0° to 90° corresponding to the effective distance through which the movable plates may be rotated. The range of the scale also represents the variation of the capacity of the condenser from its minimum to its maximum value. Scale *f*, as illustrated, is not in its correct operating position, but from this view the markings on the scale show most clearly. When the condenser is assembled, the scale is placed so that the pointer *e* rotates just above it and shows the position of the movable plates with respect to the stationary groups.

10. Fig. 4 (*a*) shows the two sets of plates *a* and *b* and their assembly in an air condenser of a type quite similar to that of Fig. 3. The plates in Fig. 4 are semicircular. The movable plates *b* are mounted on a shaft and may be rotated into the spaces between the stationary plates *a*.

In Fig. 4 (*b*) the condenser unit is mounted inside a suitable case *c*. The case affords considerable protection to the condenser from the effect of outside influences and tends to make its readings more reliable. The scale *d* in this case is mounted on the condenser shaft and rotates with it.

An extension handle *e* attached to the knob *f* provides an easy method of making fine settings of the condenser as it is easier to move a handle of this form a very small amount than it is to turn a knob a like amount. Readings of the angular position of the movable plates are made between a pointer *g* mounted on the case and the movable scale *d*. Two terminals *h* are provided, one being connected to the group of stationary plates and the other, through a flexible conductor, to the movable set of plates.

11. Fixed Condensers.—Some types of fixed condensers are formed of either square or circular aluminum plates which remain fixed in their relative positions. The air forms the dielectric. Groups are formed by connecting alternate plates, which sets then form the two plates of the condenser. This construction is commonly used in the case of standard condensers which must be very accurate and of unvarying capacity.

The usual fixed condenser is made with a solid dielectric. Under these conditions the plates are separated by the dielectric material itself, hence the plates do not require enough mechanical strength to make them self-supporting. They remain fixed in place after the condenser is once assembled and so are made of very thin sheets of conductor. As it is possible to roll tin economically into very thin sheets, it has become quite general practice to use tin-foil for the plates. A more economical use of the available space is also obtained by using thin conductors.

DIELECTRICS

CLASSIFICATION OF DIELECTRICS

12. Dielectrics may be divided into three classes, namely: gases, liquids, and solids. The first two are used in variable condensers, and in a few cases in fixed condensers. The use of solid dielectrics is confined almost exclusively to fixed condensers. The properties of condensers with no dielectric medium, that is, with a vacuum between the plates, are almost identical with those of condensers with dry air as the dielectric. Any advantage which might be gained by the use of a vacuum between the plates is so overwhelmingly counterbalanced by the cost of maintaining that condition that this type of condenser is never used.

GASEOUS DIELECTRICS

13. Air.—Air is the dielectric commonly used in condensers of the gaseous-dielectric type. Air is practically as good for that purpose as any other gas and is always available. The capacity of a condenser is nearly constant irrespective of the kind of gas used, or of the pressure of that gas. Compressed-air condensers are sometimes used; the advantage gained is due to the higher voltage which the dielectric will withstand. Condensers using compressed air are, however, not in common use because of the higher cost of construction.

Air condensers are comparatively large for a given capacity, as the plates must be made rather thick and the dielectric space is also quite large. Should the voltage across the condenser plates become high enough to arc over between plates, it would merely produce a spark discharge. As soon as the arc stopped, the high resistance of the air would be automatically reestablished, and very little permanent injury will have been done to the condenser.

In air condensers there is no conducting material between the plates to carry the charges from one plate to the other; such a condenser, therefore, will hold its charge for a con-

siderable length of time. In radio practice, however, this is hardly an advantage as condensers as generally used are required to hold their charges for only a very short period of time. As air apparently will not store up as much energy in the same space as will many other dielectrics, this type of condenser is rather bulky. The energy lost in an air condenser is negligible, as practically all the energy received from the circuit is returned to the circuit through the action of the condenser.

LIQUID DIELECTRICS

14. Oil.—Oil is the dielectric used in liquid condensers. It is apparently the only material that is suitable for the purpose. A good quality of oil that is free from mineral matter is required. Oil will stand a much higher voltage than air before it will allow a spark to pass through it. The use of oil increases the capacity of the condenser over that when air is the dielectric. Oil condensers are, therefore, sometimes used in sending stations where considerable energy at rather high voltage is radiated, since some types can store two or three times as much energy as air conductors with the same size and spacing of the plates.

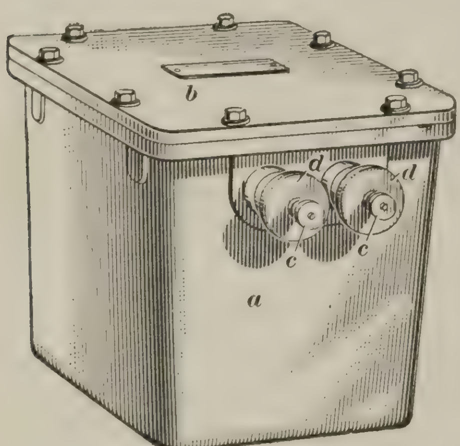


Fig. 5

15. Many types of air condensers may be used as oil condensers by simply filling the containing vessel with oil, thereby immersing the condenser plates. The container must be oil-tight, and of such material as will not be injured by the oil.

An oil condenser which is completely enclosed by a case *a* and tight-fitting cover *b* is shown in Fig. 5. The plates are of aluminum and are rigidly supported in their relative positions.

The two sets of plates of the condenser are connected to the two terminals *c*. Connection to the external circuit is made at these points.

16. Rough handling of an oil condenser is apt to cause air bubbles to be caught in the oil; these weaken the dielectric electrically. If then a high voltage is applied, a spark may be formed through some of the air bubbles between opposite plates. For this reason, it is important that this type of condenser be allowed to stand for some time in an upright position before applying full voltage, in order that the air bubbles may have a chance to rise to the surface. Should the oil puncture or break down because of a high voltage, a delay of a few seconds will permit the air bubble formed by the spark to rise to the surface and the dielectric to resume its normal characteristics. Two circular metal washers *d*, Fig. 5, on the terminals of the condenser provide a sort of safety gap. Should the applied voltage become so high that it endangers the condenser, the voltage will force a spark across the external spark gap, thus relieving the stress on the dielectric, and no bad effects will result.

The use of liquid condensers is rather limited because of the careful handling required. Some types are made, however, in which it is practically impossible to spill the oil. Greater energy losses are apt to occur in oil condensers than in air condensers, apparently on account of the greater amount of energy required to establish an electrostatic strain in the dielectric.

SOLID DIELECTRICS

17. Mica, Glass, Paper, Etc.—Condensers with solid dielectrics are in common use because of their rugged construction. There are in use several materials that permit the storage of four to eight times the amount of energy in the same space as is possible with air-dielectric condensers. Mica and glass are two of the most common materials used for dielectrics, although paraffin paper is employed in many condensers.

Condensers of the solid type are very reliable and require no attention to keep them in satisfactory condition. They are particularly applicable where the room is limited as they require a minimum of space. The plates being thin also represents some saving as to the size of the unit. The capacity of this type of condenser is fixed.

Should the dielectric be punctured by a high-voltage spark, the condenser will usually be badly damaged, if not totally ruined. The spark will form a carbon path between the plates, and the carbon, being a conductor, will prevent the accumulation of a charge on the plates. Even if a carbon path is not formed, the dielectric is punctured and sparking is liable to take place between the plates at this point with much lower voltages than when the dielectric is intact.

18. The use of solid dielectrics in many cases gives rise to leakage currents. The material between the plates is apt to carry a very small current and gradually discharge the condenser. In radio practice, however, the time during which the condenser holds its charge is very short, and the losses by the leakage currents are negligible.

Due to the high voltages which may be applied to this type of condenser, there are apt to be so-called *brush discharges*. These are usually streamers of very fine sparks passing between the plates and over the surface and edge of the intervening dielectric. These sparks are objectionable in that they represent a certain energy loss and create minor local disturbances. They seldom occur in well-designed condensers and may be reduced in many cases by immersing the plates and dielectric in oil.

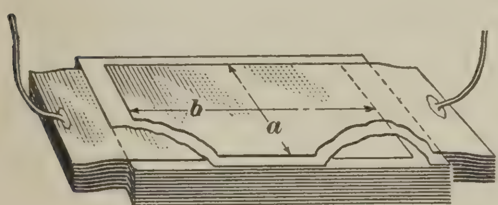
The loss occasioned by the frequent charge and discharge of solid dielectric condensers is larger in many cases than in condensers of other types. This factor is, however, seldom considered in radio practice as the loss is small with any of the dielectric materials commonly used.

19. If plates *a* and *b* of Fig. 2 are separated by a plate of glass or mica, the capacity of the condenser thus formed will be much larger than with air as the dielectric, because the

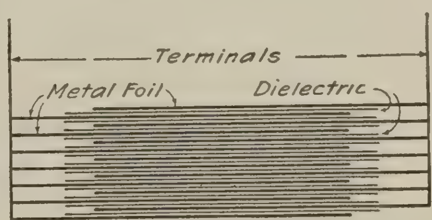
electric charges on the two plates have a greater power to react on each other through a layer of glass or mica than through a layer of air of equal thickness. Many of the common insulators may be, and actually are, used as the dielectric materials in condensers made with solid dielectrics.

The dielectric used in a condenser must be a fairly good insulator, otherwise the current would pass through it and the condenser plates would not be charged. It is impractical to make condensers with solid dielectrics which have a continuously variable capacity. Leads may be brought out by which different numbers of plates are connected to give the desired capacity effect, but here the changes in capacity are by fixed steps. This feature has been applied only in a very few cases.

The plates are placed between layers of dielectric and are supported by these layers, therefore the plates are commonly



(a)



(b)

FIG. 6

made of very thin sheets of tin-foil. In some cases they are made of copper foil, but there is practically no difference between the two as far as the electrical features are concerned.

20. Condensers with solid dielectrics are quite simple and may be easily made by assembling sheets of conducting elements and insulation so that the insulation separates the conductors. The conductors are joined electrically in two groups, alternate sheets in each group, and a terminal is connected with each group. Fig. 6 shows one method of constructing such a condenser, (*a*) being a general view with one conducting plate and one insulating sheet partly cut away, and (*b*), a diagrammatic cross-section. Sheets of mica or oiled paper generally form the insulating material, or dielectric. The active parts of the condenser plates are those separated by

dielectric, as indicated by the dimension lines *a* and *b* in view (*a*). The complete condenser made as indicated is

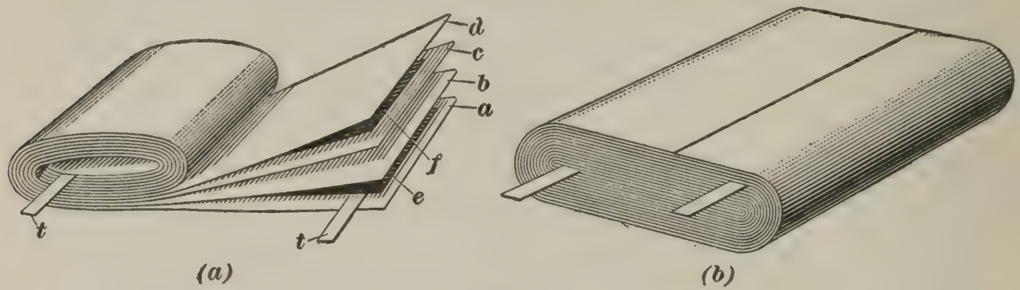


Fig. 7

enclosed between insulating sheets that are firmly pressed together and securely clamped.

21. Condensers of this type may also be made by using glass plates of any convenient size and placing them between layers of tin-foil. The foil must not extend quite to the edge of the layers of dielectric material, except at the ends where the terminals are formed, otherwise sparks may pass between the adjacent layers of the tin-foil. The whole device when assembled should be fastened securely in a suitable box, to protect it from mechanical injury and to keep the plates in their relative positions.

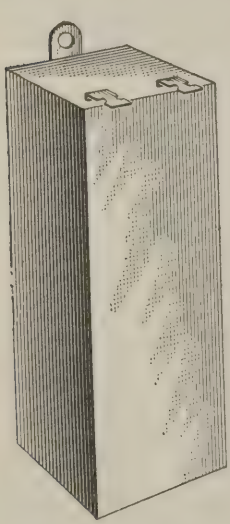


Fig. 8

22. The condenser shown in Fig. 7 (*a*) is formed of two long strips of conducting foil rolled up with layers of insulating material between them. Four long strips of thin bond paper *a, b, c,* and *d,* and two long strips of tin-foil *e* and *f* are rolled together. The strips of tin-foil are somewhat narrower than the strips of paper, and are placed between the first and second, and the third and fourth strips of paper, as indicated, thus bringing two layers of paper between the adjacent layers of tin-foil. Thin strips of metal *t* are laid adjacent to the respective layers of tin-foil during the process of rolling and are allowed to project from the finished roll, as shown in Fig. 7 (*b*), to form terminals.

The roll is boiled in hot paraffin so as to impregnate it thoroughly and expel all moisture. While hot it is subjected to heavy pressure, expelling all superfluous paraffin and bringing the plates very closely together. When completed, it is placed in a sealed can and presents the appearance shown Fig. 8.

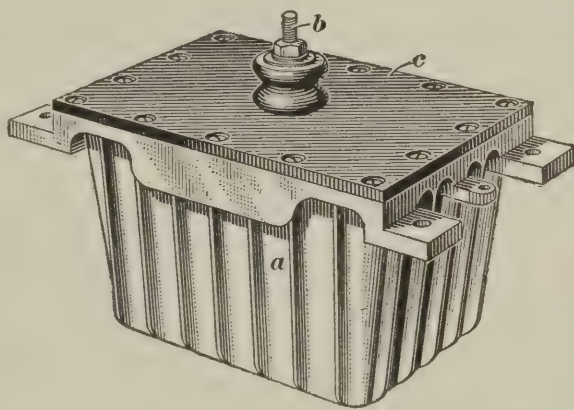


Fig. 9

23. Fig. 9 shows the exterior of a condenser using mica as a dielectric. A condenser of this type will withstand high voltage and for a given plate surface will store a comparatively large amount of energy. The aluminum case *a* forms one terminal. The other terminal is shown at *b* and is mounted on the cover *c* made of insulating material. Heavy lugs on the case serve as supports when mounting the condenser.

CAPACITY OF CONDENSERS

24. Farad.—The capacity of a condenser is dependent upon the amount of energy it will store. The capacity of any condenser, expressed in *farads,* is equal to the result obtained by dividing the coulombs of electricity of a complete charge by the electromotive force impressed on the terminals. A smaller and more convenient unit, the *microfarad,* is commonly used to designate the capacity of condensers. A farad equals 1,000,000 microfarads, or one microfarad equals one-millionth of a farad. Condensers used in radio practice seldom have capacities as great as a microfarad. Another unit of capacity, sometimes used, is the *centimeter,* which is one nine hundred thousandth of a microfarad.

25. Conditions Affecting Capacity.—The actual shape of the plates has very little influence on the capacity of a condenser. In general, the capacity may be said to depend

upon the area of the plates exposed to each other, the distance between them, and the particular dielectric used. The presence of moisture in the dielectric is very apt to change both the capacity and the losses in a condenser; this is especially true of air condensers. Increasing the area of the plates exposed increases the capacity. This is the procedure followed in variable condensers in which the capacity is increased by increasing the surface area of the movable plates that is exposed to the surface area of the stationary plates.

Placing condensers in parallel will be equivalent to increasing the area of the plates, and the capacity of the combination will be equal to the sum of the individual capacities. The distance between the plates may be decreased, which will also increase the capacity within certain limits. The capacity depends to a very large extent upon the dielectric used, being least with gases and highest with some solids. Also, the capacity of condensers made of certain dielectric materials is reduced appreciably when they are used on radio-frequency circuits.

26. The size of condenser to use in any case, where reliable calculations are not possible, may best be determined by experiment. For this purpose a variable condenser is most suitable, as it may be varied until the desired results are obtained. Where accurate adjustment is not necessary and the required size is known, fixed condensers may be used. Features of design, such as power to be handled, portability, space available, reliability, etc., must be considered.

VERNIER CONDENSER ATTACHMENT

27. The variable condenser as usually constructed consists of several plates joined together. In some cases it is rather difficult to make very small adjustments in capacity with accuracy. The addition of a couple of plates, called a *vernier,* or *inter-degree attachment,* operated by a separate handle, will provide a means for securing accurate settings and fine adjustments.

A condenser with a vernier attachment is shown in Figs. 10 and 11. As far as possible, corresponding parts are indicated by similar letters. The stationary plates of the main group are shown at *a* and the movable group of plates at *b*. The shaft carrying the movable plates passes through the bearing *c* and extends into the knob *d*. The scale *e* is mounted next to and turns with the knob; indications of the setting being read with reference to the fixed line on *f*. A small insulator *g* prevents the edges of the movable plates from coming into contact with the stationary plates at that point. Adjustment of the main plates of the condenser is accomplished in the usual manner.

28. In Fig. 10 the vernier attachment includes the stationary plate *h* and the movable plate *i* placed a short distance

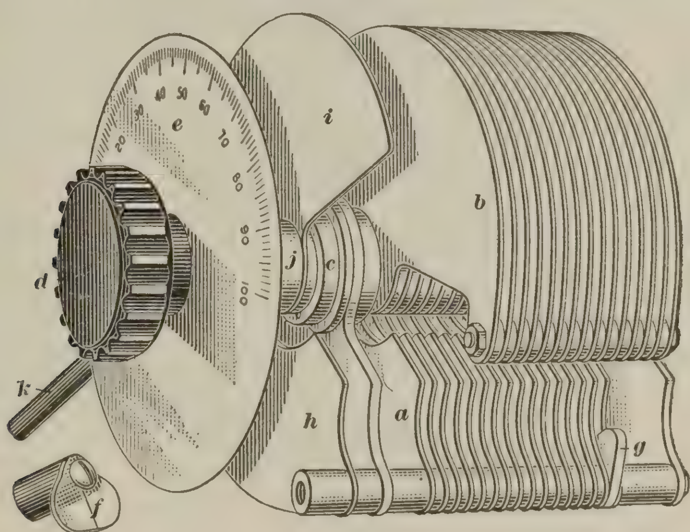


FIG. 10

from the main groups of plates. The relative position of these plates is varied by means of the sleeve *j* carrying a handle *k*. These plates are connected in parallel with those of the main condenser and when the position of the movable plate is varied, will change the total capacity of the condenser by a small amount. The sleeve *j* is free to rotate on the main shaft. Plate *i* is mounted on one end of the sleeve, while the handle *k* is screwed into a raised section of the sleeve. Plate *i* is thus rigidly connected to the handle *k* and any motion of the handle will cause the movable plate to change its position by a corresponding amount. The long handle *k* permits accurate

adjustment of the vernier device without bringing the hand too close to the plates and thereby disturbing the adjustment by the capacity effect between the hand and the plates.

The whole condenser may be enclosed in a case of conducting material, which may be grounded, in which case there will be no capacity influence from any surrounding objects. The clips *l* and *m*, Fig. 11, hold the handle *k* in either of its extreme positions. The terminals *n* provide for connection to the

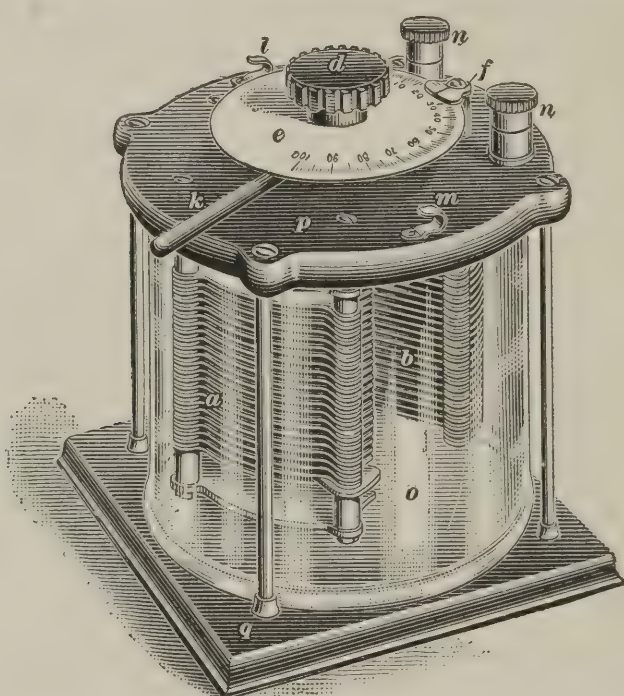


Fig. 11

external circuit. The glass jar *o* may be filled with oil in which case the capacity of the condenser will be increased. The condenser may also, when an oil dielectric is used, be used on higher voltages than when air is employed. The cover *p* actually supports the condenser plates by means of screws that hold the supporting posts for the stationary plates and the shaft to which the movable plates are attached. A base *q* is also provided upon which the condenser is mounted.

ACTION ON DIRECT AND ALTERNATING CURRENTS

29. The fact should be kept in mind that a condenser in a circuit will prevent the continuous passage of direct current, but will permit alternating current to pass into and out of it. When a condenser is connected to a direct-current source, it will be charged, but as the dielectric is an insulating medium, no current can pass through it. There will be, however, current in the circuit until the condenser is fully charged. When the condenser is disconnected from the source and a conductor is connected across the terminals of the two plates, there will be a rapid passage of current through the conductor and the charges on the two plates will be neutralized. The condenser will then be in condition to receive another charge.

Should the applied electromotive force be reversed, the condenser plates will be charged, but the plates will receive charges opposite in polarity to those which they formerly possessed. When these reversals follow each other in rapid succession, as in an alternating-current circuit, the condenser is rapidly charged and discharged. Except for the small losses, all the energy taken by the condenser during a charge is returned to the circuit by the discharge.

DETECTORS

ACTION OF DETECTORS

30. Purpose.—The signals radiated into space as radio waves are of a high frequency. These high-frequency oscillations when interrupted by the receiving antenna are still at the radio frequency, and hence will not produce signals distinguishable by the human ear. In a broad sense, the name *detector* means that portion of the receiving apparatus which, in conjunction with a signal indicator, translates the received radio-frequency currents into intelligible form. In this Section, however, the name detector will apply to the single device which detects, or rectifies, the high-frequency alternating currents, although, as with many other devices, a detector of this type would be of very little use by itself. For the present only the fundamental action of and descriptions of various types of detectors will be taken up; a consideration of the combined pieces of apparatus is left for the following Sections.

31. Operation.—In a general way, the signals received by the detecting device consist of groups of radio-frequency, alternating-current waves. The action of the detector, briefly expressed, is to rectify the current so that each wave-train forms a single unidirectional current impulse. In reality this is due to the combination of radio devices comprising the complete detector of the receiving set. The resulting pulsations which are at an audio frequency, are the ones which are actually received by the operator and produce dots and dashes corresponding to those made by the sending operator.

The action of a detector depends upon its rectifying property, which is effective on any alternating current impressed upon it. It has been found that contact between a metal point and almost any metallic crystal or between two such crystals presents a

very high resistance to a current in one direction and a comparatively low resistance to the passage of a current in the opposite direction. Many materials possess this property to some extent, but those in general use are commonly called *crystals,* and the device then becomes a *crystal detector.* Crystals are selected from materials the rectifying properties of which have been determined by tests.

A competitor of the crystal detector, and one which bids fair to outrival it, is the *electron-tube* detector. The action of the latter is to rectify the incoming signals in a manner somewhat different from that mentioned above and which will be treated in a succeeding Section.

32. Characteristics.—A detector which will give the strongest possible signals, and a high degree of reliability is usually desired. By this is meant that the detector should be of such a nature that it can be easily and quickly set in operation, and that it will hold its setting for a reasonable length of time. To be satisfactory, a detector should give an accurate rectification of the signals, without unnecessarily decreasing their strength. A crystal which will fulfill all these requirements has not been found, although several materials have come into general use which operate quite satisfactorily. As particular characteristics fit a detector to operate more satisfactorily under certain conditions than others, it is desirable to select the type of detector which will give the best results under existing conditions.

CRYSTAL DETECTORS

33. Galena.—A detector employing a galena crystal is shown in Fig. 12. The crystal *a* is mounted rigidly in a containing cup through which electrical connection is made to one of the terminals. The lower end of the small coil spring *b* presses against the crystal and makes contact with it. The metal spring is supported and adjusted by a handle *c,* which, being mounted in a ball-and-socket joint, permits a very large range of adjustment. In this manner the contact point may be placed on nearly any desired spot on the surface of the

crystal. The supporting post *d* provides a mounting for the handle and also completes the electrical path between the metal contact point and the remaining terminal. The glass tube *e* is used to protect the rather delicate parts from injury, particularly from moisture. The whole device is mounted upon a suitable base *f* of insulating material.

34. It is a peculiarity of all crystals to have some points on their surface that give much stronger signals than will other points. A point at which signals come in strong is said to be *sensitive*. It is often difficult to locate a sensitive spot and, for that reason, the metal point is mounted in such a way that it may be moved over the surface of the crystal, in order that several positions may be tried until a sensitive point is found. Signals may often be heard when the metal point is on practically any position on the crystal, but certain points can usually be found at which the signals are much stronger. Some crystals of a certain material will in many cases give much more satisfactory results than will others of the same material. In most cases, however, good crystals can be found only by testing. Some materials will remain sensitive, or provide a good path for the incoming waves of current, for a considerable time after setting the point, while others will maintain a good contact for only a few minutes.

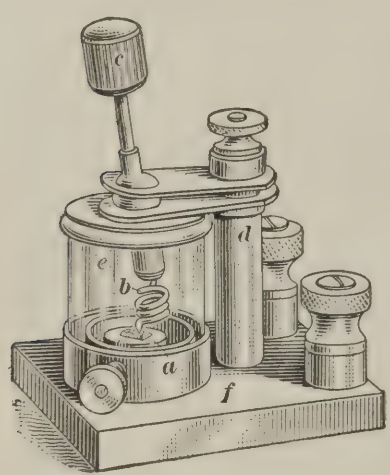


Fig. 12

35. Galena crystals possess the general characteristics of sensitiveness, but a sensitive point is sometimes hard to find and does not remain in good condition for a very long time. The metal point should be small and exert a light pressure against the galena crystal. A satisfactory arrangement is shown in Fig. 12, in which the point is an extension of the phosphor-bronze coil spring *b*. A good galena crystal will give very good and very strong signals.

36. Crystal Mountings.—A good arrangement of three typical crystals mounted on a common base is shown in Fig. 13. The three crystals used in this particular case are, *a* silicon, *b* carborundum, and *c* galena. Since the mounting arrangement is the same in all three cases, only one will be described in detail. The vertical mounting post *d* and the corresponding posts for the other crystals act as supports for the crystals and are electrically connected to the terminal binding post *e*. The threaded shaft *f* passes through the ball *g* of a ball-and-socket joint, the clamp of which is shown at *h*. Turning knob *i* moves shaft *f* toward or away from the crystal *a*. A rod *j* is mounted within shaft *f* as is also a small spring which tends to push the rod and its attached contact point *k* toward the crystal. Adjustment may be made so that a constant and uniform pressure is exerted by the point against the crystal. The knob *l* mounted on the extension of rod *j* provides a means of pulling the contact point away from the crystal while making trials to locate a sensitive point. The base *m* of insulating material serves as a support for the crystals and their auxiliary apparatus.

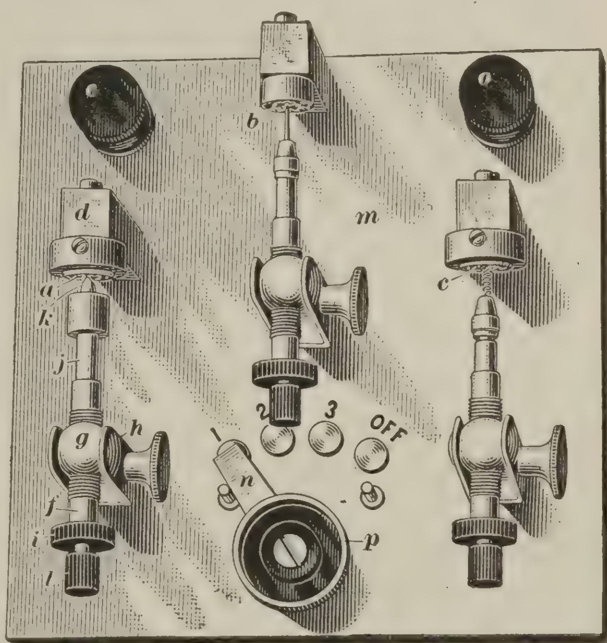


FIG. 13

The clamp *h* is connected to point *1* of the switch. The blade *n* is connected to terminal *o*. When the blade is on point *1*, the silicon crystal is in circuit between terminals *e* and *o*. Point *2* of the switch is connected to the contact point resting on crystal *b*; and point *3* to the contact point of crystal *c*. Since the crystal mountings are all connected to terminal *e*, any one of the three crystals may be cut into circuit by means

of the switch. The crystals may be mounted vertically or horizontally. The terminal *o* might be connected to the crystals and the switch to terminal *e* without changing the operation of the apparatus.

37. Silicon.—The crystal *a*, Fig. 13, of silicon has a contact point *k*, formed from an antimony crystal pressing against it. The rectifier action occurs at the contact between the point and the crystals. It has been found that this combination of minerals will operate satisfactorily and that such a detector will maintain a sensitive setting under the influence of high voltages from the antenna due to static. The contact point of antimony is not necessarily pointed sharply, as such a point is hard to maintain, and the operation is usually satisfactory with a rather blunt crystal.

38. Carborundum.—The carborundum crystal is of the same material as that of which carborundum abrasive wheels are made. A crystal of this material is mounted at *b*, Fig. 13. Experiments have proved that for best operation the contact should be made by means of a metal point very firmly pressed against the crystal. For this reason a steel needle, such as is used on a phonograph, will prove entirely satisfactory, and it should be forced against the crystal with considerable pressure.

The main characteristic of the carborundum crystal is that signals may be received from nearly any point on the surface at which good contact is made, and the detector will keep its setting for some time. The signals are usually not as strong as when some other detectors are used, but the reliability feature does much to commend it. Another point which adds to the reliability of the carborundum crystal is the fact that its rectifying qualities are not injured by dirt, successful operation continuing as long as the needle makes a firm contact with the crystal. In many cases, satisfactory operation has been obtained by using a wide spring which exerts a heavy pressure against the highest point on the crystal.

39. The galena crystal *c*, Fig. 13, is the detector in use when the switch blade *n* is on contact point *3*. This arrangement is, in general, similar to that shown in Fig. 12. In Fig. 13,

however, the crystal is not protected by a glass case. The metal contact point is the straightened end of the wire forming the small helical spring mounting. The helical spring serves to exert a constant but light pressure of the point against the galena crystal.

40. Zincite and Bornite.—Another combination which has come into considerable use is that employing zincite and bornite crystals. The detector is quite frequently arranged, as is the antimony-silicon combination shown in Fig. 13, with the zincite stationary and the bornite mounted on the movable arm. This detector will give very good results, is rather easily set, and will maintain a sensitive setting for a reasonable length of time. Other crystals and combinations of crystals have been used as detectors.

SPARK GAPS

GENERAL CONSIDERATIONS

41. Definition.—A **spark gap,** as used in radio practice is a device which will complete a circuit in the power supply line of a radio set, and later will break this circuit, thereby setting up high-frequency oscillations in another circuit. The successful operation of the spark gap used in a sending station affects materially the radiation of current from that particular station and consequently the distance over which communication may be established.

42. Operation.—In a general way, the operation of a spark gap is as follows: An alternating electromotive force is applied to the terminals of the spark gap at a frequency of 60 to 900 cycles. The spark gap includes a short air gap between the conducting terminals across which the voltage is impressed. When the voltage reaches a certain high value, it will rupture the air and a spark discharge will take place. When the proper devices are connected in circuit with the spark gap, the spark discharge will be at radio frequency, and the energy may be transmitted to an antenna and radiated

into space. The main requirements of a spark gap may be stated as follows and the operation is often in the sequence given: it must keep the circuit open until the proper voltage is impressed upon its terminals; it should offer a rather low resistance path for the spark discharge that gives rise to the radio-frequency oscillations; and it should reestablish its original conditions immediately upon cessation of the discharge.

When the above conditions are fulfilled, communication between stations will be at its best and the strength of the signals will be a maximum. When the gap is not operating properly, there will be a large loss of energy and the range of communication will be greatly reduced. Certain characteristics of the circuits are apt to cause considerable interference by an improperly adjusted spark gap, or one which does not operate correctly under existing conditions.

43. Nature of Spark Discharge.—A spark discharge is usually caused by an oscillatory current and hence produces an oscillatory magnetic field around the spark and around the conductors connected on each side of the spark gap. This magnetic field increases in strength as the current increases, and decreases as the current decreases. Consequently the magnetic field has the same frequency as the oscillating current and is proportional to it in strength. Such rapid changes in the magnetic field surrounding the oscillating current produce disturbances that are supposed to travel as waves through space. These *electromagnetic waves,* which are also called *Hertzian waves,* may be produced with such energy as to travel long distances. These are generally supposed to be the waves that establish radio communication from station to station. It has also been proved that electromagnetic waves travel through space with the same velocity as light, although they have a different frequency of vibration.

44. Just before a spark passes between two conductors separated by air or other dielectric, the dielectric is electrically strained; that is, an electric disturbance or displacement is produced in the surrounding region. Moreover, about the same kind of an electrostatic field is set up by this disturbance

as the magnetic field set up by a current of electricity, except that the lines of force of the electrostatic and electromagnetic fields are at right angles to each other. When the spark does pass, an oscillating current is established and an oscillating magnetic field is set up around the path of the current as an axis. This field restores part of its energy to the circuit as the current dies away, and part is doubtless radiated into space.

When a voltage difference is equalized by a sudden discharge, the electric tension in the dielectric is relieved, and displacement currents, or electric waves, are said to be sent out into space. As a result of the electrostatic and electromagnetic disturbances, whether they are distinct or are one and the same phenomenon, disturbances in the form of waves are sent out into space in all directions; hence the energy due to these waves that is received at various distances decreases rapidly as the distance from the originating point increases.

TYPES OF SPARK GAPS

45. Simple Spark Gap.—A very simple spark gap is shown in Fig. 14. The air gap proper *a* is formed between two rods *b* and *c*, which being movable permit adjustment of the length of the air path. The rods are loosely mounted in holes in the top of posts *d* and *e*, but may be secured in any desired position by means

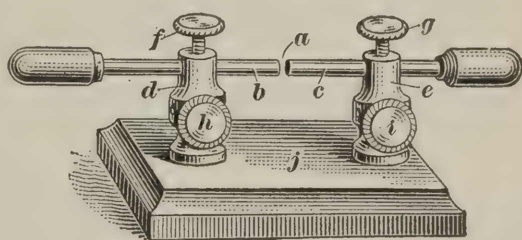


Fig. 14

of screws *f* and *g*. Screws *h* and *i* serve to hold terminal wires in holes in posts *d* and *e*. The whole device is mounted upon a base *j* of some good insulating material. The rods *b* and *c* are called electrodes, although this term is sometimes applied only to that section which is near the air gap. Almost any good conducting metal may be used for the electrodes. Zinc, copper, and monel metal are commonly used for this purpose. Monel metal is a natural alloy of nickel, copper, and a small percentage of other elements. Electrodes made

of these materials will operate for a long time without requiring a new adjustment.

46. The air gap forms a very good insulating section, and prevents the passage of current through the spark gap at ordinary voltages. When the voltage is increased to a sufficient value, a spark or series of sparks will be established between the electrodes. Electrically speaking, the air is actually broken down, and in such a state forms a relatively good conductor between the electrodes. As soon as the spark discharge has passed, the arc must be suppressed. In low-power sets this may be accomplished by the use of large electrodes freely exposed to the air. The electrodes will be kept comparatively cool and will operate satisfactorily.

47. Spark Gaps With Flanged Electrodes.—In cases where sparking will cause heating of plain electrodes, large cooling surfaces are provided. The spark gap shown in Fig. 15 has several large flanges *a* mounted on the electrodes *b*. These flanges assist in dissipating the heat caused by the sparks and keep the electrodes much cooler than would be the case with plain electrodes. The spark gap shown in Fig. 15 will operate successfully on a larger current than the one shown in Fig. 14. Screw threads on rod *c*, Fig. 15, fitting into threads in posts *d* allow fine adjustments of the length of the air gap. A spring within each post keeps its electrode from moving after an adjustment has been made.

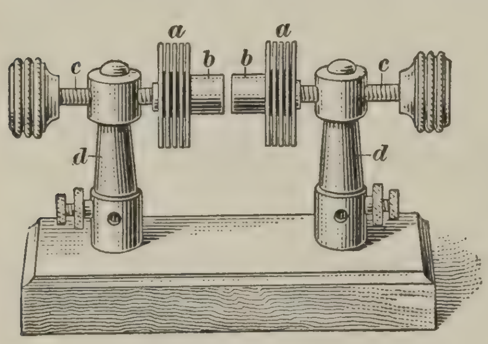


Fig. 15

48. When adjusting a spark gap of this type it is well to remember that the electrodes should not be separated so as to draw the longest possible spark, hoping thereby to obtain a larger amount of radiation. Instead, the spark gap should be adjusted so that a strong fat spark is produced. The radiation and operation will then be at its best.

49. Spark gaps of the types illustrated are very liable to become heated if used for some time on sending sets other than the smallest. Even on the smaller sets it is desirable from an operating point of view to use a spark gap which will effectually interrupt the spark as soon as the main discharge has passed. The chief difficulty experienced in the operation of the plain spark gap is the tendency of the discharge to take the form of an arc rather than a spark, making impossible a pure oscillatory discharge and a clear note. A very good, but rarely used, method for compelling a spark to discharge and not arc, is by directing a blast of air from a blower so that it acts at right angles to the spark path. One of the electrodes may be made hollow and air blown through this electrode will be directed against the spark. Both these methods will produce a fairly pure spark note, and in addition will have the advantage that the air blast tends to conserve the sparking surfaces by keeping them cool.

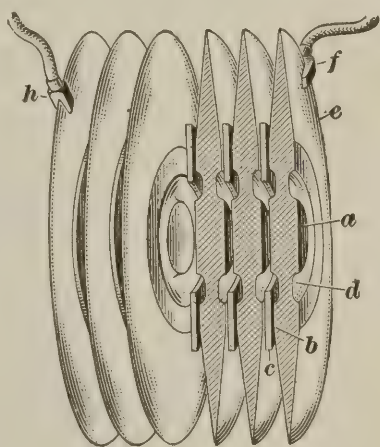


Fig. 16

50. Quenched Spark Gap. The operation of a spark gap may be improved to a large extent by using several short gaps in series instead of a single long gap. The quenched spark gap consists of several circular copper plates of special design, a few of which are shown in Fig. 16. The sparking surface *a* is very smooth and varies from ½ to 1 inch in diameter, depending upon the amount of energy that the gap must handle. These plates are placed together in series with their sparking surfaces adjacent, and are separated at *b* by mica or fiber washers *c* which insulate the plates and keep the sparking surfaces at the proper distance. A circular groove *d* is cut in each of the plates surrounding the sparking surface, so that the inner edge of the washer extends over it, thus preventing the spark from forming across the edge of the washer, which would soon carbonize the washers and cause a short circuit

between the plates. The sides of the insulating rings *c* are coated when assembling, with shellac or some similar substance, and the whole set is clamped together, forming air-tight chambers for the spark discharges. The gaps being entirely enclosed, operate with very little noise and may be placed quite close to the rest of the set with no discomfort to the operator. Extensions or fins *e* on the outer edges of the copper plates form excellent radiators and dissipate the heat rapidly. The larger sizes of quenched spark gaps have a blast of air playing over the outside fins *e*.

The immediate quenching of the spark is brought about partly by the fact that the oscillatory discharge occurs in an

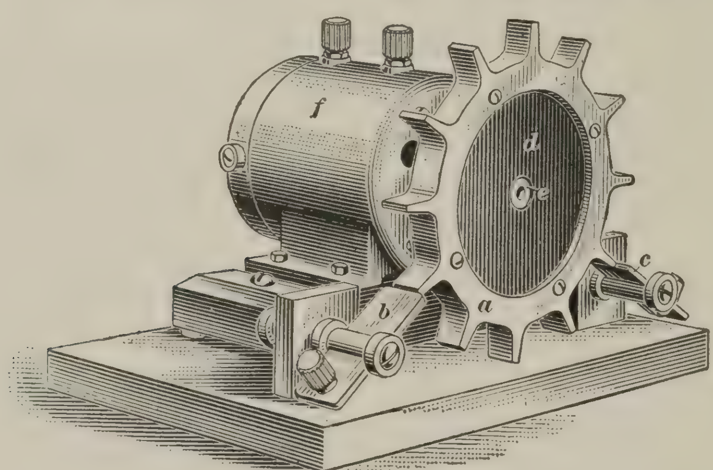


FIG. 17

air-tight chamber, and partly by the good cooling effect obtained by distributing the discharge among a number of relatively small gaps. This gap gives a high, clear spark note, and has been used in many up-to-date installations. Any number of plates may be connected, the number used depending upon the set with which the gap is to be operated. In many cases a permanent connection is made to one end of the gap, and the other terminal is arranged to connect any desired number of gaps by means of a suitable clamp which may be attached to the fin of any of the plates as indicated at *f* and *h*, Fig. 16.

51. Rotary Spark Gap.—A **rotary spark gap** is one with one or more rotating electrodes, the movements of the

electrodes assisting materially in keeping the sparking surfaces cool and in controlling the discharge. Fig. 17 shows a rotary spark gap with its small driving motor. The main part of the rotor *a* is of cast copper with broad thin teeth formed on its outer edge. These teeth in their rotation pass very close to the stationary electrodes *b* and *c* which also form terminals to the external circuit. When the teeth are opposite the stationary electrodes, as shown, the air gap is very short.

A rather low voltage impressed across the terminals will establish a spark across the air gaps. If the rotor is turned a short distance the length of the air gap will be rapidly increased until it becomes sufficient to extinguish the spark. Continued rotation will bring the next pair of teeth opposite the electrodes and permit another short period of spark discharges. There will be a spark discharge every time the teeth pass the stationary electrodes and the resulting tone of the set will depend directly upon the speed of rotation of the rotor. The shape of the teeth is such that they blow a current of air over the electrodes *b* and *c* to keep them cool. The rapid lengthening of the air gap just after the spark starts, causes the spark to be suppressed in a very short time, which is a very desirable characteristic in a spark gap.

52. The rotor *a* of Fig. 17 is mounted on a disk of insulating material *d* and rotates with it. An extension *e* of the shaft of the motor *f* provides a support for the rotating disk. The speed of the motor may be varied over certain limits to produce a good tone for the spark gap.

In many cases the rotary spark gap is mounted on the end of the alternator shaft, thereby eliminating the cost of a separate motor. By proper adjustment of the rotor of the spark gap, the discharge may be made to occur at the moment of the maximum values of the positive and negative waves of the alternating current. This regular occurrence of the discharges produces a pure musical tone.

TELEPHONE APPARATUS

DEFINITION OF TERMS

53. Telephony is the art of transmitting sounds between distant points by means of fluctuations of an electric current. This definition applies to both wire telephony and radio telephony, the carrying mediums being electric conductors in the first case and the ether in the second case. For the purpose of telephony, sound may be said to be the sensation produced by vibration of the air on the ear drum. When one person talks with another the speaker sets in motion a series of air waves which when striking against the delicate membrane of the listener's ear produce the sensation called *sound*. In electric telephony the transmission of sound is accomplished by making one plate, or diaphragm, at the sending station, take up or respond to, the wave of the sound to be transmitted, and causing, by electric means, another diaphragm at the receiving end of the line to vibrate as nearly as possible in exact accordance with the first, thus producing the original sound.

TELEPHONE RECEIVERS

54. Fundamental Forms.—In its simplest form, the **telephone receiver,** as shown in Fig. 18, consists of a thin, soft-iron diaphragm P mounted close to but not touching one pole of the permanent magnet $N S$. A fine wire C is coiled around one end of the magnet and the terminals of this coil are connected directly in the circuit in which the instrument is to be used. The diaphragm is rigidly supported at its outer edge, but the center portion will be curved slightly toward the magnet because of the attraction between the diaphragm and the magnet. If a current is sent through the coil in such a

direction that the lines of force set up by it coincide with those of the permanent magnet, the strength of the magnet will be increased and the diaphragm will be drawn closer to the pole. If, however, a current is sent through the coil in such a direction as to set up lines of force opposing those of the magnet, the strength of the magnet will be diminished and the diaphragm will spring farther from the pole.

55. If a current that varies in value but is always in the same direction is sent through the coil, the lines of force induced in the magnet will increase while the current is increasing, and decrease while the current is decreasing. Thus, a varying pull on the diaphragm will cause vibrations that will

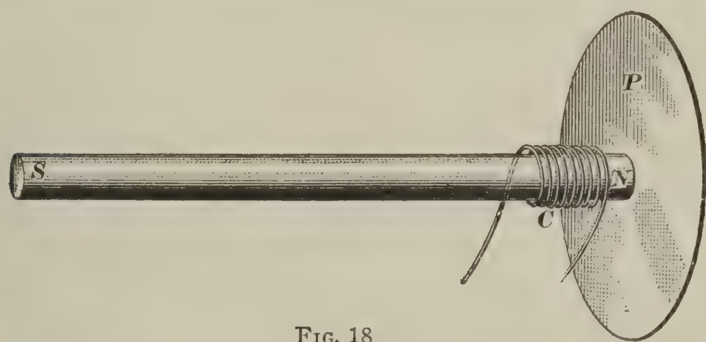


Fig. 18

be in harmony with the changes in current whether the lines induced by the coil are in the same direction as those of the magnet or not.

If the current is an alternating one, that is, one that is first in one direction and then in the other, the lines set up in the magnet will change their direction every time the current changes its direction. They will thus, while in one direction add to the strength of the magnet, and while in the other direction diminish it, producing a varying pull on the diaphragm.

56. The telephone receiver is affected by the fluctuating currents corresponding to sound waves and translates these currents into distinguishable sounds. The diaphragm of this simple device, like the diaphragm of the reproducer of a phonograph, is capable of emitting the most complex sounds; in fact, it is capable of imitating with a fair degree of accuracy

practically all of the sounds of the human voice, of musical instruments, or other sounds made up of many complicated wave combinations.

57. Standard Type.—A cross-sectional view of a standard type telephone receiver is shown in Fig. 19. A barrel or shell *a* is used to protect the component parts of the receiver, and may be made of some insulating material or in some cases is made of metal finished with an enamel coating. The ear piece *b* screws onto the shell and serves to cover the diaphragm end of the receiver except for a small hole in its center through which sound waves are permitted to escape. The permanent magnet *c* is U-shaped, and has both poles projecting close to the diaphragm *d* to give as strong a pull as possible. The pole

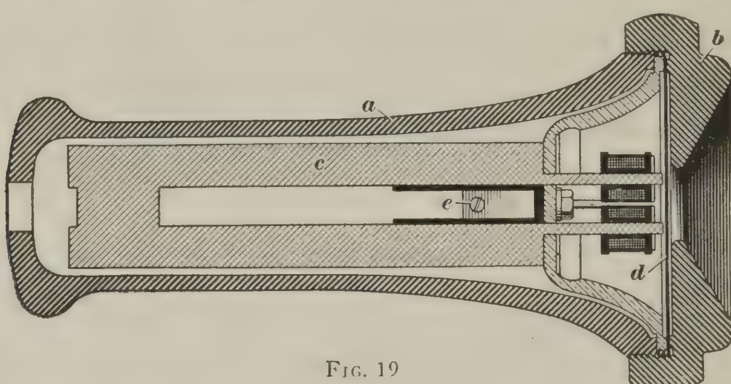


Fig. 19

projections carry the windings which are equally distributed between the two coils, and which are connected to the terminals at *e*, only one of which is shown. Bringing both poles of the permanent magnet close to the diaphragm increases the number of lines of force effective on the diaphragm and increases considerably the sensitiveness of the receiving unit.

58. Watch-Case Type.—The construction of a compact form of telephone receiver, known as the *watch-case* receiver, is shown in Fig. 20; view (*a*) shows a section and view (*b*) shows the end with the ear piece and diaphragm removed. When the receiver is equipped with a head band, as shown in view (*a*), it forms a *head-set*, although the more common practice is to use two receiver units. In that case one receiver

is placed at each end of the head band fitting securely over both ears, and helping to exclude local sounds. A simple adjusting device is then placed at each end so the receivers may be made to fit closely against the ears, yet without so much pressure that their use becomes tiresome.

59. Although the principle of operation is the same as in the larger hand receiver, the construction and design is necessarily varied to decrease both the size and the weight. The shell *a* consists of a case usually of metal, threaded externally to engage an internal screw-thread on the hard-

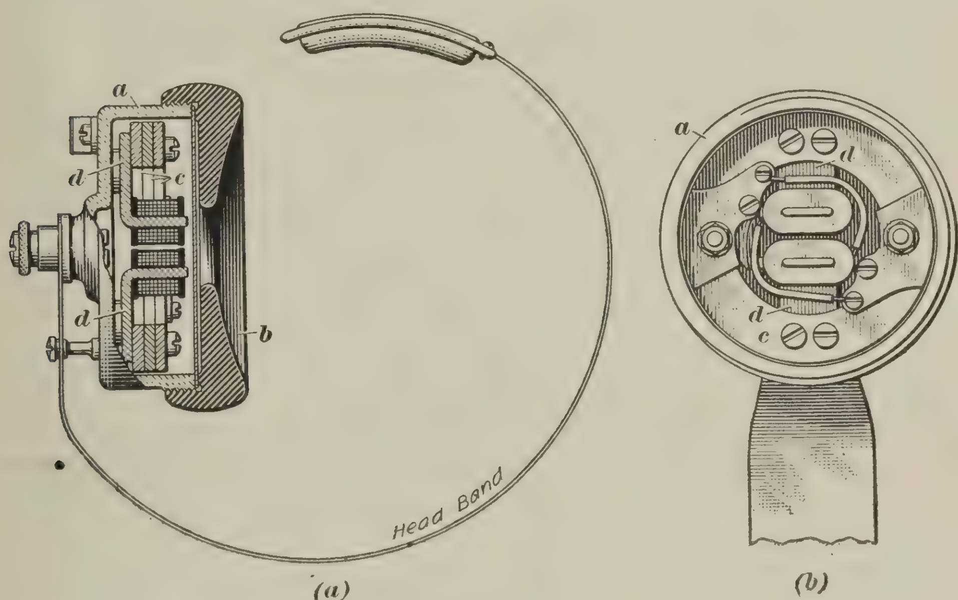


FIG. 20

rubber ear piece *b*. The magnets are built up of flat steel rings *c*, so magnetized that the opposite sides of their circumferences are of different polarities. The **L**-shaped pole pieces *d*, which reach nearly to the diaphragm and carry the magnet coils, are attached to the north and south poles of the steel rings. In many cases the magnets are not made of complete rings, but approximately half circles are used for the magnet forms. The extensions carrying the coils are then fastened to the ends of the permanent magnet. The diaphragm is of thin iron and is clamped between the body *a* of the shell and the ear cap *b*.

60. Rating.—Telephone receivers are usually rated according to their total resistance, the value being expressed in ohms. As used in wire telephony, the resistance usually lies between 10 and 100 ohms, although higher values are used under some circumstances. In radio practice it is considered desirable to use receivers of high resistance in order to balance more nearly the high resistance of other parts of the receiving circuit. As devices of relatively high resistance are commonly used, the resistance of telephone receivers is usually around 2,000 or 3,000 ohms. In some low-resistance receiving sets, which are usually so specified, the low-resistance telephones are preferred.

In order to obtain the desired electromagnetic pull, it is necessary to use many turns of wire on the coils. The space for the windings is limited; therefore, a very fine wire is used which makes a high-resistance coil. It is difficult to determine the number of turns of wire used in a telephone receiver, after it is assembled, hence rating by turns is not used. The resistance, however, is in a fair measure related to the length of wire and consequently to the number of turns, and, being readily obtained at any time, the resistance is customarily used for rating purposes. Telephone receivers of 2,000 ohms will be found well adapted to ordinary radio work, although in case a particular set is used, the recommendation of the manufacturer should be sought and followed.

TELEPHONE TRANSMITTERS

61. Fundamental Form.—A **telephone transmitter** is an instrument which takes up the vibrations of the sound to be transmitted, and causes corresponding fluctuations of electric current in the circuit of which it is a part. The type of receiver illustrated in Fig. 18 will work very satisfactorily as a transmitter, but as such, it is limited to communication over very short distances because of the extremely small value of the electromotive force generated by the movement of the diaphragm. Connecting two such instruments by two conductors furnishes the fundamental principle of the

wire telephone, and conversation may be carried on by utilizing the telephones and the wire as a connecting medium.

62. Variable-Resistance Type.—The action of the instrument usually employed as a standard telephone transmitter is such as to alter the resistance of the circuit and thus produce variations in the strength of the current. The instrument is very sensitive and for that reason is often called a *microphone.* The resistance between two bodies in light contact can be made to vary by slight changes in the pressure applied to the bodies. Such a transmitter, since it does not generate an electromotive force, must necessarily contain a source of electromotive force connected in the transmitter cir-

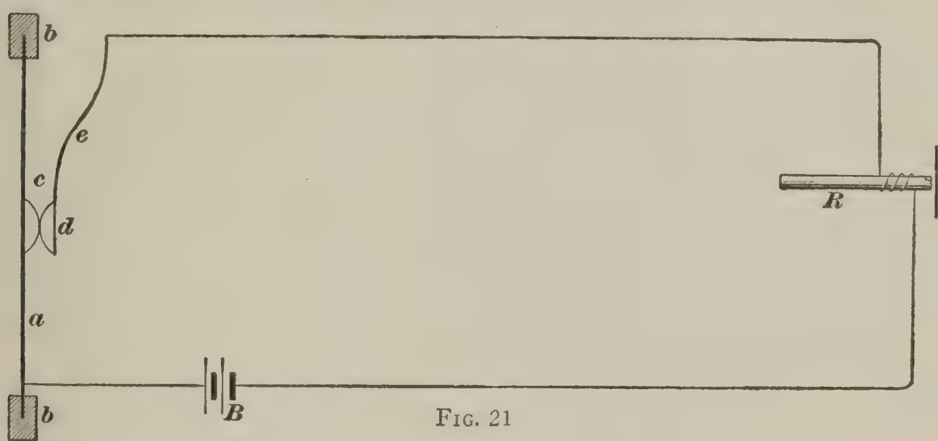


FIG. 21

cuit. The device acts as a valve, or throttle, controlling the current in that circuit. Though all conductors possess the property of giving a variable contact resistance with changing pressure to a certain extent, it has been found to be greatest in carbon.

63. A trasnmitter depending upon the variable-contact resistance principle is indicated in Fig. 21. A diaphragm *a* supported in a stationary ring *b* carries a carbon button *c* against which another carbon button *d*, mounted on a spring *e*, is lightly pressed. The two carbon buttons form part of an electric circuit, which also includes a battery *B* and a telephone receiver *R*. The pressure between the buttons is light, so that small variations in the pressure cause large variations in the resistance of the contact. Sound waves striking against the diaphragm cause it to vibrate; these vibrations vary the resis-

tance of the loose contact, the line current is varied accordingly, and the diaphragm of the receiver is thus made to vibrate in unison with the transmitter diaphragm.

64. The variable-resistance transmitter in its most common form is the *granular-carbon transmitter,* in which vibrations of the diaphragm increase and decrease the pressure on a chamber of carbon particles, or granules, thus varying the resistance of a multitude of loose contacts. The construction as actually used in practice is shown in the sectional view of Fig. 22 and the three-quarter rear view of Fig. 23. The hard-rubber mouthpiece *a,* Fig. 22, is threaded to engage a screw-thread on the internal ring of the front covering *b,* which fits into the outer rim of the shell *c.* The front and rear carbon disks, which form the *electrodes,* or main contact surfaces, are shown in heavy black on either side of the granular carbon *d.* The rear electrode is soldered to a brass disk having a small projecting shaft *e* that is screwed into the bottom, or rear, of the brass cup *f.* The front electrode is attached to a brass disk from which a threaded stud passes through the diaphragm *g* to permit of the front electrode being clamped rigidly to the diaphragm by means of the two small nuts *h.* The cup *f* containing the granular carbon is closed by a mica washer which is clamped to the cup by a threaded ring *i* and to the front electrode plate by a threaded ring *j.* Therefore, the only relative motion possible between the two electrodes is that permitted by the flexing of this mica washer. The washer serves

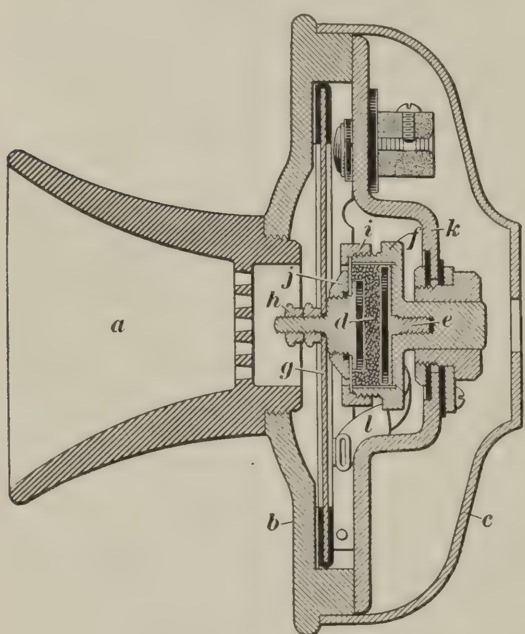


Fig. 22

to close the carbon chamber, thus preventing the granular carbon from falling out and moisture from getting in, and at the same time provides the necessary play between the electrodes. The cup *f*, the electrodes, granular carbon, front electrode plate, mica washer, and clamping rings are assembled at the factory and form the variable-resistance part of the transmitter. This entire structure is fastened to the bridge *k* of both figures, which in turn is attached to the front piece *b*. The fact that the rear electrode is rigidly supported is responsible for the name *solid back,* which is often applied to this type of transmitter.

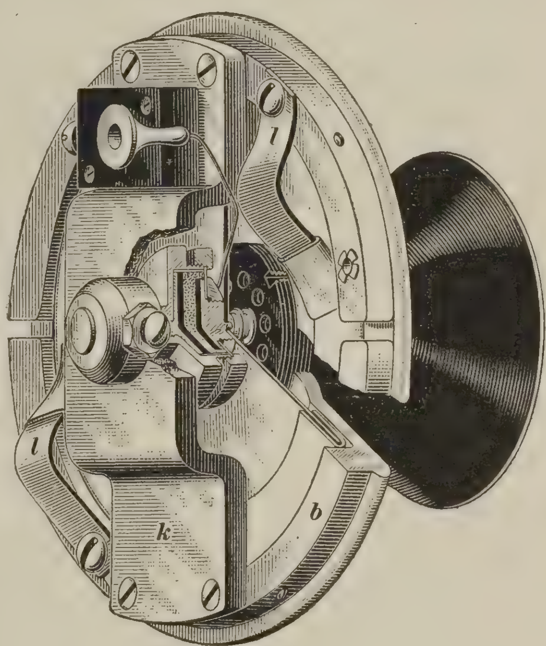


Fig. 23

Two steel springs *l* are fastened to the case so that their free ends which are provided with insulating cushions of soft rubber, rest upon the diaphragm. By reducing the flexibility of the diaphragm, they eliminate to a large extent the confusion of sounds that would otherwise result from its free movement. Among the many kinds of transmitters on the market nearly all employ the foregoing principles, although they may vary to some extent due to different designs adopted by the many manufacturers. The variation in resistance of any transmitter is undoubtedly caused by the variation in area of the surfaces of granules and electrodes that are in contact at any instant and not by any compression within the carbon itself.

65. Other Types.—Transmitters such as have been described have been found to be entirely satisfactory in wire telephone practice where the current in no case is very large. In radio it is necessary to transmit a much larger amount of

energy than is ordinarily used in wire telephony, with a consequent larger current through the transmitter. If the current is increased too much, the carbon granules will overheat and may even fuse together, rendering the device worthless until the old carbon is replaced with new granules. Using two or more similar transmitters in parallel offers a partial solution as the current will divide and not be excessively large in any case. Some speaking-tube arrangement must be devised to divide equally the sound waves among the various transmitters.

66. An arrangement which has been used to a very limited extent depends upon the variation of resistance of a column of water or of an electrolyte with changes in its diameter. A stream of falling water in the one case forms part of the transmitting circuit. By a rather sensitive and complicated arrangement of parts, any sound waves striking a diaphragm cause changes in the diameter of the water column. This changes the resistance of the path and consequently of the transmitting circuit. The chief advantage of this transmitter is the fact that it can be used to vary rather large electric currents.

DAMPED-WAVE RADIO TELEGRAPHY

TRANSMITTING

GENERAL CLASSIFICATION OF RADIO COMMUNICATION

1. Radio communication, considered from the standpoint of the nature of the waves by which communication is established between stations, may be divided into two classes. In the class employing **damped waves,** a series of wave-trains is sent out, each of which trains consists of a group of damped radio-frequency waves. The term damped as used here means that the succeeding waves in the short wave-trains are of decreasing amplitude. Practically, there may be any number of waves in each train, although United States Government regulations prohibit the use of radio signals with less than about 23 waves per train. These waves are not usually continuous; that is, the trains do not ordinarily overlap, or even join their neighbors. In the second class, employing **undamped waves,** use is made of radio-frequency waves, which form a continuous series of waves of constant amplitude, representing a true alternating current. The latter class is confined largely to radio-telephony and will be taken up in detail in a succeeding Section.

2. The individual trains of damped high-frequency waves are usually produced by the oscillatory discharge of a current established by a high voltage impressed on an air gap. This

high voltage may be generated directly, but is more often an accumulated voltage, gathered by a condenser of proper size. It is essential, however, that the spark gap be connected to a radiating circuit, such as an open oscillator or antenna, in order that the signals may be sent out into the ether.

RADIO SENDING STATIONS

SIMPLEST TYPE

3. A very simple type of sending station is represented by the circuit diagram shown in Fig. 1. The parts of the circuit and devices used are indicated by the conventional symbols, which have been illustrated and described in another Section. The first step in the operation of the station would be the closing of the key *a*. As soon as the voltage of the alternator *b* reaches a sufficient value, the spark gap *c* will break down, and an oscillatory discharge will take place across it. This oscillatory discharge will produce a strong effect on the antenna system *d* and, due to the high frequency of the oscillating discharge, a considerable amount of energy will be radiated out into the ether. The number of oscillations in each discharge will be quite small, and will in any case depend upon the electrical characteristics of the set as a whole, as will also the damping, or decrease of the successive waves in a train. If the spark gap is properly adjusted, there will be a spark discharge for every half-cycle of the alternator, and the number of wave-trains per second will be equal to twice the alternator frequency. A succession of groups of damped oscillations will be produced in the antenna circuit, and, as long as the key is closed, a series of damped-wave trains will be radiated into space. By proper manipulation of the sending key, the dots and dashes of the radio-telegraph code are produced, dashes consisting of a longer series of wave-trains than do the dots.

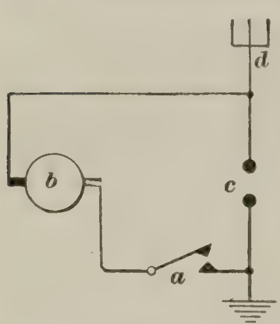


Fig. 1

4. A marked disadvantage of using an alternator connected directly across a spark gap in the antenna is the fact that an alternator of very high voltage must be used in order to obtain an appreciable amount of energy radiation. This is rather objectionable from an operating point of view, as it is a source of danger to the operator, as well as from a constructional point of view, because it requires a machine of special design. The arrangement is also very inefficient as a radiator, and is not used in practice.

SENDING SET WITH VOLTAGE TRANSFORMER

5. An alternator of fairly low voltage may be used as the source of energy in the sending set illustrated in Fig. 2. The primary winding *a* of an iron-core voltage transformer is connected in series with the alternator *b* and key *c*. The secondary winding *d* of the transformer is connected across the spark gap *e*, which in turn is connected between the antenna *f* and ground. When the key is closed, a current of low voltage and rather low frequency passes through the primary winding of the transformer, and induces a current of the same frequency, but at a higher voltage, in the secondary winding. The action taking place in the secondary circuit is quite similar to that which has been described, in that the high voltage will cause the spark gap to break down and a wave-train of high-frequency oscillations will be produced for every half-cycle of the alternator current.

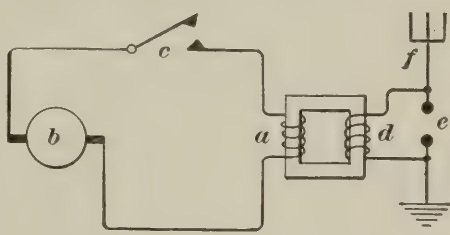


FIG. 2

6. The use of a step-up voltage transformer gives a much larger radiation output and range for the set than is otherwise attainable, as it is possible to impress several thousand volts across the antenna system. The lower voltage of the primary circuit is an advantage as the alternator need not be designed and constructed to generate such high voltages, as would other-

wise be necessary. The person operating the sending key is relieved from the hazard of coming in accidental contact with any high-voltage wires.

With manipulation of the sending key, the machine is required to furnish full load at one instant, and no load at the next, with consequent wide variation in speed caused by the sudden and large change of output. As a relief measure, the sending key may be shunted by a resistance. When the key is opened, the primary circuit will still be closed through the auxiliary resistance by extra contact points on the key. The resistance should be of such a value that it will decrease the voltage in the secondary circuit to such an extent as to prevent a discharge across the spark gap. Although more energy is taken from the generator with no increase in radiation, this arrangement is desirable as it causes the transmitted signals to have greater uniformity; a feature of importance to the receiving operator.

7. The length of the wave radiated into the ether depends upon the electrical characteristics of the circuit in which the high-frequency oscillations are produced. In the sets which have just been described, no means of adjustment are provided in the antenna circuit, and consequently signals of only one wave-length can be transmitted. As the two main features affecting the wave-length are the inductance and capacity of the producing circuit, the introduction of devices possessing these properties will change the oscillating period of the antenna circuit, and, consequently, the length of the emitted wave. Connecting either an inductance coil or a condenser between the antenna and the ground will give the desired result, the size of the device used depending upon the change required.

8. The systems that have been described make use of a spark gap connected directly in series in the antenna system, and across the power-supply circuit. For these reasons the antenna circuit is said to be *directly excited,* that is, the high-frequency oscillations are both produced in, and radiated by, this circuit. The spark gap introduces a high resistance in

the antenna circuit, which causes a very rapid damping of the trains of oscillating high-frequency waves. The wave radiated in such a case is very *broad,* that is, the receiving station may pick up the incoming signals over a considerable range of wave-length adjustments. This would prevent other stations, operating on nearly the same wave-length, from tuning out undesirable signals. By the method just described a low number of oscillations results from a spark discharge, and the use of this type of apparatus has been prohibited. In order to produce a wave that will not have such high-damping characteristics, the oscillatory discharge is produced in a local circuit in which the operating conditions may be more easily and accurately controlled. The high-frequency currents are then transferred to the antenna system from the *indirect excitation circuit* by means of a transformer.

HIGH-FREQUENCY OSCILLATIONS

9. The devices which may be used in a circuit to produce radio-frequency discharges are represented in Fig. 3, and comprise a condenser *a,* a coil *b* possessing inductance, and a spark gap *c.* Now let a charge of electricity from some outside source be given the condenser; a positive charge on plate *d,* and a negative charge on plate *e.* The condenser will continue to store up the energy given it until a point is reached at which the voltage between the plates is high enough to cause the spark gap *c* to break down and allow current to pass between the electrodes of the spark gap. At that instant the outside source of power is removed, but as the plate *d* is positive, there is a rush of current from plate *d,* across spark gap *c,* through the inductance *b,* and on to plate *e* as indicated by the heavy arrows. Electricity would flow only until the charges were equalized between the two plates, were it not for the inductance coil included in the circuit. The presence of the inductance coil, however, makes itself manifest by its fly-

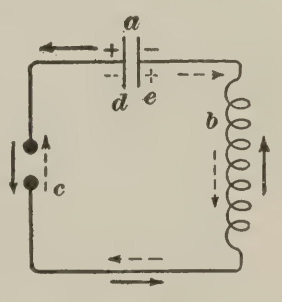


FIG. 3

wheel action, and compels the current to keep on even though the charges on the plates have been temporarily neutralized. The current passing to plate *e* now establishes on it a positive charge, and plate *d* has a negative charge induced on it. The condition now is just the opposite from that at the start, so that there is a rush of current from plate *e*, through the coil *b*, across the air gap, and on to plate *d*, as indicated by the dotted arrows. The flywheel action of the inductance coil again comes into play and forces the current to continue beyond the point of neutralization of the charges on the plates, so that plate *d* again becomes positive and plate *e* negative; that is, the condition is similar, in regard to polarity of the plates, to that at the very first. The process keeps on repeating itself, but during each reversal of the current there is some energy lost due to the resistance of the circuit, and finally the voltage is not high enough to force a current across the spark gap, and all action ceases.

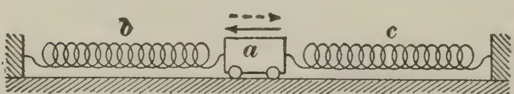


FIG. 4

10. During the action just described, electricity flows around the circuit first in one direction and then in the other, decreasing in strength with each reversal. It is therefore a damped alternating current and, due to the excessively high frequency of between 20,000 and 2,000,000 cycles per second, it is commonly termed an **oscillating current.**

11. A mechanical analogy may be employed to explain the electrical phenomenon just described. A heavy weight *a*, Fig. 4, corresponds to the inductance coil of Fig. 3, and the plates of the condenser of that figure are represented by the springs *b* and *c* in Fig. 4. The springs are fastened at their outer ends, their inner ends resting against the weight. The weight is mounted on wheels so as to run on a track. If a force is applied to the weight *a* to *move* it in the direction of the heavy arrow, the spring *b* will store up energy while being compressed. If the force is removed, spring *b* will compel the weight to move in the direction of the dotted arrow, until the weight is in its neutral position, or until the pressure of

the two springs is equal. However, the inertia of the weight will carry it on past its former resting place and spring c will be compressed. The weight thus transmits energy from one spring to the other and back again. The action thus closely corresponds with that described for the oscillating circuit, except that in the case of the heavy weight, the frequency of the back and forth motion is rather low. The succeeding energy transfers and movements of the carriage become smaller and smaller, due to frictional resistance, and thus further resemble the electrical conditions in which the succeeding current waves are decreased by the electrical resistance of the circuit.

12. The frequency of the oscillations in the electrical circuit, Fig. 3, is determined solely by the capacity of the condenser and the inductance of the inductance coil, the spark gap having no appreciable effect. In actual practice some provision is usually made whereby the condenser or the inductance coil, or both of these devices, may be adjusted, thus varying the frequency of the oscillatory discharge. If the capacity of the condenser is increased, the frequency of the oscillations is decreased, and vice versa; and if the inductance of the coil is increased, the frequency is decreased, and vice versa. The introduction of resistance in any oscillating circuit does not change the frequency of the oscillating current, but merely reduces the amplitude of the succeeding waves in the wave-trains.

13. In the case just considered there was only one application of power from an outside source to the circuit, but many oscillations of current were established. These oscillations have such a high frequency, and all occur in such a brief interval of time, that the train would appear to an observer to be only a single spark. Further application of power from the outside source may be made, and there will be a train of oscillations produced for each application of power. In the usual practice, the source of power is an alternating electromotive force, and a group of oscillations is produced for each current reversal.

POWER SUPPLY FOR OSCILLATING CIRCUITS

14. Fig. 5 shows an alternator *a*, connected to an oscillating circuit, through an iron-core transformer *b*. The transformer may be dispensed with in case the voltage of the alternator is high enough to break down the spark gap *c*, but such is seldom the case. When a spark gap connected across the terminals of the secondary winding of the power transformer breaks down, a path of relatively low resistance is formed across the secondary. The transformer windings, therefore, may be burned out by the excessively large current resulting unless *choke coils d*, which consist simply of solenoids with iron cores, are inserted in series in the circuit; usually one is placed at each of the terminals of the secondary coil.

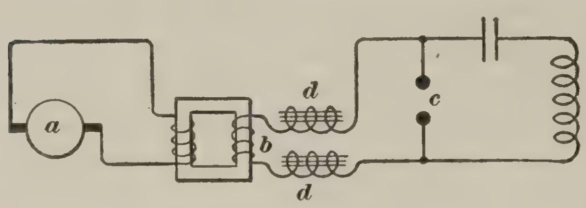


Fig. 5

15. The necessity for using choke coils is obviated to a considerable extent by the circuit arrangement of Fig. 6, as the coil on the right, which possesses inductance, is in series with the spark gap, and thus limits the current in the secondary circuit. On account of the comparatively low opposition of a condenser to high-frequency surges, such currents will tend to pass in and out of the condenser, which thus acts as a shunt to the secondary coil.

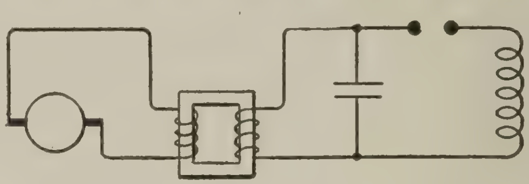


Fig. 6

OSCILLATING CIRCUIT CONNECTED TO ANTENNA

16. The circuit arrangement, Fig. 6, is shown in Fig. 7, with the addition of an antenna system. An inductance coil *a* in the antenna circuit is so placed as to cut the lines of force established by coil *b* of the oscillating circuit. The inductance

coil *b* then acts as the primary and coil *a* as the secondary of an oscillation transformer. Energy is transferred from the oscillating circuit to the antenna, or radiating, circuit by induction. The antenna circuit will readily receive a large part of the energy from the closed oscillating circuit, if the product of the inductance and capacity of the one is approximately equal to that of the other. If these products are not nearly equal, very little energy will be transferred. In other words, the natural frequency or period of oscillation of each circuit must be the same, or approximately so. Two circuits whose natural periods of vibration are the same are said to be in **resonance,** which is the desirable condition just referred to.

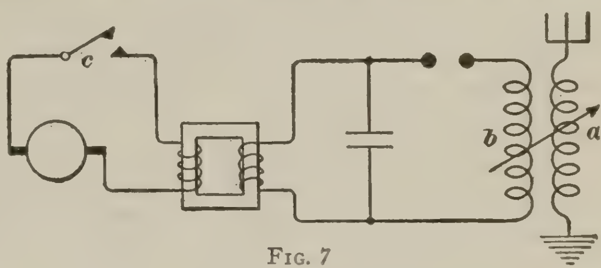


Fig. 7

17. The action of one circuit on the other is somewhat similar to that of two tuning forks placed near each other. If they are both tuned to the same pitch, or key, and if one of them is struck, it will vibrate at its natural frequency. Now if it be suddenly stopped it will be found that the other tuning fork is vibrating although it has not been touched in any way. If the two forks are not of the same pitch, and the first one be struck and then stopped, it will be found that the second one is not vibrating.

TRANSMITTING APPARATUS AND DEVICES

DEVICES IN ANTENNA CIRCUIT

18. As has been mentioned, the antenna is the part of the station apparatus which actually radiates the radio signals. To perform its function properly, it must radiate a large amount of the energy which it receives without causing undue losses or distortion of the emitted wave. A spark gap is inserted in the circuit between the antenna and the ground in Figs. 1 and 2, while an inductance coil *a* occupies that position

in Fig. 7. The action is, however, identical in the two cases, as the primary use of these devices is to produce a high-frequency oscillating current in the antenna circuit. The antenna and the earth are always at opposite potentials; with current in one direction, the antenna is positive and the earth negative, and when the current reverses, the antenna is negative and earth positive, and so on. There are, then, lines of force created between the antenna and the earth, and these lines of force represent the energy actually thrown off or radiated by the high-frequency oscillations. The alternately positive and negative lines of force which travel through the ether correspond to the waves sent out over the surface of the water when a stone is thrown into a pond.

POWER-SUPPLY CIRCUIT

19. With the usual arrangement, the power-supply circuit includes an operating key *c*, Fig. 7, used to open or close the circuit through the primary coil of the power transformer. Transmission of waves is established only when the key is closed. A key is sometimes used in series in the field circuit of the alternator to interrupt the current in that circuit, instead of breaking the rather large current in the power circuit. In this latter case, however, the action is somewhat sluggish, as the field must be built up and decreased with each closing and opening of the key, resulting in a slow sending speed. A relay key in the alternator circuit will usually produce the best results where large currents are to be interrupted; satisfactory operation with a relay key has even been obtained by connecting it in the secondary circuit of the transformer.

A radio **transmitting,** or **sending, station** comprises all the apparatus and auxiliary devices necessary to generate and radiate radio-frequency oscillations into the ether. The sending station shown in Fig. 7 represents one of the most simple arrangements which will give satisfactory results, but the underlying principles apply to many sets which are apparently more complicated, as well as to others which, though considerably simpler, give good results.

20. It is perfectly feasible to use a commercial alternator delivering 25- or 60-cycle current as the source of energy; in fact, many stations are operated with energy at one of these frequencies received from a local electric central station. If a spark gap of the ordinary type is used in the oscillating circuit, the tone of that station as heard in a receiving set will be very poor and it will be difficult to receive messages. A rotary spark gap should be used, giving somewhere between 500 and 1,000 spark discharges per second. While this does not give a pure musical note in the receiving set, it is of a good audio frequency and is readily copied.

Alternators are manufactured which deliver 500- or 900-cycle currents. With such alternators the frequency of the spark discharge is quite good, and an ordinary spark gap may be used in the oscillating circuit. The tone produced is naturally musical, but if the spark gap is not properly adjusted, the note may become ragged or rough. For best operation, the use of a rotary spark gap is recommended as the interruption of the energy supplied to the oscillating circuit is very rapid and positive.

21. In many instances the rotor of the spark gap is mounted on an extension of the alternator shaft, and rotates with it, thus eliminating the necessity for using a separate machine to drive the gap rotor. The stationary electrodes are placed in such positions that a spark discharge will occur the instant the maximum value of each alternating voltage wave is reached. This type of spark gap is sometimes known as a *synchronous spark gap,* as its frequency of interruption is related to the frequency of the current. The note produced by this gap is more clear and musical than that produced by a spark gap operating at some other speed. The latter practice is, however, justified in case two or more stations are to be operating simultaneously on nearly the same wave-lengths, as the signals of the different stations may then be distinguished from each other. The quenched spark gap will also operate quite satisfactorily with the 500- and 900-cycle sources of current.

22. If the source of energy is a commercial supply line, it is customary to use an iron-core transformer of the usual type to step up the voltage from that of the supply circuit to several thousand volts. If the frequency is 500 or 900 cycles or thereabout, iron-core transformers are likewise used, but they must be of special design or trouble will be experienced with overheating. Due to the characteristics of iron-core transformers, they cannot be used on radio-frequency circuits, and air-core transformers must be used. Such a transformer is represented by coils *a* and *b* in Fig. 7, its purpose being to transfer the high-frequency currents from the oscillating circuit to the antenna, and simultaneously to raise the voltage to some extent. Some means of varying the number of turns of wire effective in the primary and secondary circuits as well as for varying the coupling between them is usually provided in air-core transformers, although such has not been indicated in some of the figures.

CHANGING THE WAVE-LENGTH

23. The wave-length is dependent upon the values of the inductance and the capacity of the circuit, which explains the reason for making the inductance and the capacity in the oscillating circuit variable. Adjustments are made so as to give the values that will produce a radiated wave of the desired length. Varying the length of the spark gap or coupling changes the wave-length to only a slight extent, if at all. A more important consideration is that if the coupling is too close, a broad wave will be radiated, which, due to the consequent interference produced, will be very undesirable. This method of producing a broad wave finds practical application in the case of distress signals emanating from a ship station, which signals have absolute precedence over all other radio communication. Here the operator desires to attract complete attention, which he does by using close coupling and maximum power. If after a reasonable time, the operator called does not answer, any one reasonably close may reply. All other stations must preserve absolute silence until the transfer of distress messages has been completed. As sending stations are

required by common courtesy to radiate only enough energy to establish satisfactory communication, it is necessary that the output be decreased when working with near-by stations. One of the most convenient methods of accomplishing this, is by decreasing the coupling between the windings of the high-frequency transformer. Another fairly common method is to decrease the input to the power transformer by decreasing the voltage applied thereto. An objection to the latter method which is not true of the former, is that it is usually necessary to change the adjustments of the various tuning devices after any changes of voltage have been made.

AUTOTRANSFORMER USED BETWEEN OSCILLATING AND ANTENNA CIRCUITS

24. The use of an air-core autotransformer between the oscillating and antenna circuits gives quite good operating characteristics. Such an arrangement is represented in Fig. 8, in which the inductance coil *a* is the autotransformer. Sliding contacts at *b* and *c* permit changes in the number of turns of wire included in the primary and secondary circuits, respectively. The coupling between these circuits cannot be changed except for the small amount made possible by using different turns of wire on the transformer. This constitutes the chief objection to the adoption of the autotransformer for this use, although it is employed in some small-range sets.

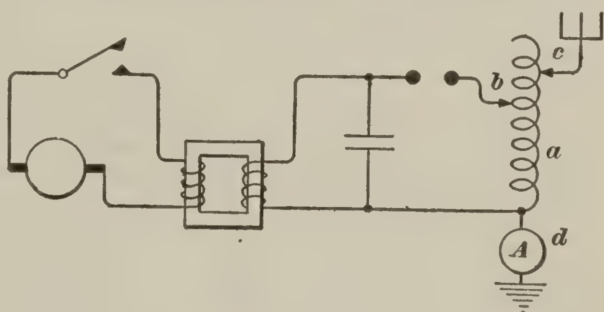


FIG. 8

An expansion-type ammeter *d* is included in the antenna circuit of this sending set. It is usually located between the lower end of the autotransformer and the ground. A reading of the ammeter gives indirectly an indication of the amount of energy radiated by the set, but does not directly do so because the instrument does not indicate watts.

25. The condenser used in the oscillating circuit of a radio transmitting set is of rather large capacity, and may or may not be so arranged that its capacity is adjustable. Due to the very high voltages impressed across the plates, a dielectric which will withstand a high electrical strain is required. In the earlier types of stations extensive use was made of condensers with glass dielectrics, either in the form of jars or flat plates. This form of condenser was rather bulky and subject to frequent puncture by high-voltage surges, which would render it useless. It has largely been superseded by the smaller sized and more rugged condensers using mica or oil as the dielectric. Where space is not an object, air condensers may be used, the air in some instances being placed under pressure, the better to withstand high voltages. In a few cases the capacity may be arranged to be varied by changing the external circuit connections, but this is inconvenient as compared with the facility with which the inductance may be varied in a transmitting circuit.

POWER-BUZZER TRANSMITTER

26. A very simple transmitting set utilizing a battery as the direct-current source of energy is represented in Fig. 9. The high-frequency buzzer *a* may be one of ordinary design operating with a few dry cells. The capacity of the condenser *b* need not be large.

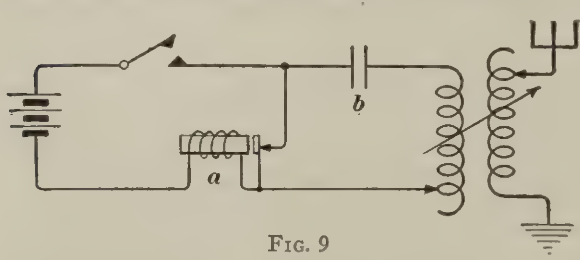


Fig. 9

The range of this set is necessarily rather limited, but for that very reason is recommended for communication with near-by stations. The power required and interference produced are both a minimum, factors which are of real importance.

ARRANGEMENT FOR USING A DIRECT-CURRENT SUPPLY

27. When only direct current is available, a motor-generator set may be used to convert the energy into alternating current of suitable frequency for the operation of any of the sending sets which have been described. Another arrangement is to use an induction or spark coil with its primary or input winding connected in the supply line. The vibrator on the coil, or any other circuit interrupter, may be used to open and close the supply circuit so that a pulsating current passes through the primary winding. This pulsating current establishes an alternating electromotive force in the secondary winding which is impressed on the oscillating circuit. The current is changed in the oscillating circuit so as to have radio frequency which is suitable for transmission. For short distances and where interference is not a consideration, the secondary of the induction coil has been connected across the spark gap which formed a part of the antenna circuit, resulting in a circuit arrangement very similar to Fig. 2. A sending key is commonly connected in the primary circuit.

OPERATING A SENDING STATION

28. The smooth operation of stations depends on the correct adjustment of the apparatus. In some sets very few adjustments of the apparatus can be made, while in the more elaborate sets many adjustments are possible. The procedure to be followed can only be determined by carefully noting the instructions furnished by the manufacturer. In the absence of such instructions, the following general suggestions are of value.

A careful inspection of the wiring and connections is desirable in every case, and is necessary if the operator is not familiar with that particular style of apparatus. This will often prevent damage to expensive equipment as well as protect the operator. If the source of energy is a power line or a storage battery it is necessary to see that whichever is used

is properly connected. If an alternator or other electrical apparatus such as a rotary spark gap must be started, this should be done at the outset. When these devices are operating properly, the key may be closed and the oscillating circuit tuned to the proper wave-length, the antenna circuit being opened or else very loosely coupled. A *wavemeter* is a device by means of which the length of a radio-frequency wave may be measured, and will be described later. The wavemeter is loosely coupled to the oscillating circuit, which circuit is then tuned to the desired wave-length by varying its capacity and inductance. For this operation the wavemeter is set at the desired wave-length, and the adjustments in the oscillating circuit are made until maximum response is observed in the wavemeter. The high-frequency oscillating circuit is then generating a wave of the desired length.

29. The next step is to adjust the coupling between the oscillating and the antenna circuits to some medium value, and the antenna circuit is then tuned to the desired wave-length. This is accomplished by varying the inductance in the antenna circuit until an ammeter or other current-indicating device in that circuit gives a maximum indication. If the current indication is nearly constant for a considerable variation of inductance, it means that the emitted wave is very broad or that transmission is on more than one wave-length. The coupling should be decreased until it is certain that transmission is being effected on a single wave-length, or if this is not practicable both the circuits under consideration should be adjusted until such conditions are reached.

It is desirable to make still further adjustments in order to secure maximum current in the antenna. The length of the spark gap should be varied until the antenna-current indication is maximum, and the spark tone is good and clear. It is also of benefit to again test the adjustments of the coupling and of the condenser and inductance coils to be sure that operation is at its best.

WAVE SHAPES IN VARIOUS CIRCUITS

30. A consideration of the shapes of the various current waves in the different circuits may help to make clear the changes and steps through which the energy must pass before it is finally radiated out into space. The shapes of the waves in the various circuits are shown in Fig. 10, the curves being given in consecutive order. The curve in view (*a*) represents

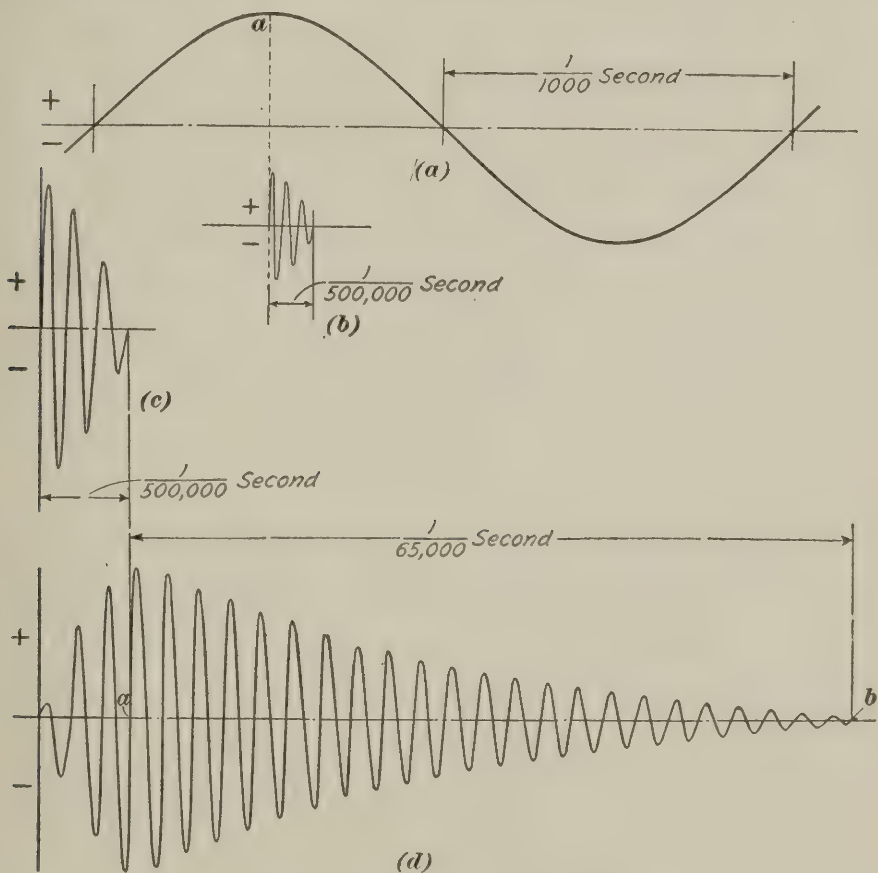


Fig. 10

the shape of the current-supply wave, which in this case has been taken to be from a 500-cycle alternator. The voltage curve would also have a similar shape. The curves in views (*b*) and (*c*), which are drawn to different scales but have identical values, indicate the shape of the wave across the spark gap, while the curve in view (*d*) shows the shape of the wave of the antenna circuit. The reason for duplicating

the curve of the wave across the spark gap is so that in the following explanation the curves of views (*a*) and (*b*) and the curves of views (*c*) and (*d*) may be readily compared.

31. Only one complete cycle of the 500-cycle supply current is represented in view (*a*), Fig. 10. If when the current is at some point near its maximum value, as at *a*, view (*a*), the electrodes of the synchronous spark gap are opposite each other, the voltage will break down the gap, and a high-frequency spark discharge will take place. The energy furnished by the alternator has been stored up in the condenser of the oscillating circuit, and is now permitted to discharge, thus producing a high-frequency current in that circuit. With continued movement of the rotor, the gap rapidly lengthens, and interrupts the spark after a very few oscillations have occurred, in this case three. The oscillations occur very rapidly, the frequency of a 200-meter wave, which is quite common, being close to 1,500,000 cycles per second. The total time for the three cycles represented in view (*b*) is thus very short, in fact much shorter than is indicated by the relative lengths of the curves, views (*a*) and (*b*). However, for purposes of explanation, the relation is sufficiently accurate. The three high-frequency waves constituting the oscillatory discharge are commonly called a *wave-train*, which term has been used before in this same connection. For convenience, only three cycles are here represented; in practice, however, the train usually consists of a greater number of waves.

The tone of the spark may be varied by changing the number of points at which the spark gap discharges. For example, if a discharge occurs at every other peak of the impressed voltage wave, the tone will be decidedly different than that of a spark discharge occurring at every maximum point on that same wave. When a 60-cycle source of supply is used, it is necessary to produce several spark discharges for each voltage cycle in order to secure a fairly high tone. In this case the spark may occur when the condenser is only partly charged, or possibly not charged at all, with the result that the spark tone will be rather rough and hard to read at the receiving set.

32. The train of waves shown in view (*d*), Fig. 10, is dependent on the train of waves of view (*c*). The train of waves of view (*c*) represents the high-frequency current established in the oscillating circuit by the discharge of the condenser across the spark gap. This current induces lines of force around the inductance coil forming a part of its circuit, which lines of force interlink with the inductance coil of the antenna circuit. The energy is rapidly transferred from the oscillating circuit to the antenna circuit, as is shown by the high damping of the curve, view (*c*), and the correspondingly rapid increase of the curve, view (*d*). It should be noted that the first three cycles of the curve, view (*d*), increase at approximately the same rate as that at which the curve, view (*c*), is decreased. At point *a*, view (*d*), the energy in the oscillating circuit has been removed, and the spark gap ceases to pass sparks. It should be noted that point *a*, view (*d*), is directly below the right end of the train of waves, view (*c*). The open spark gap prevents transfer of energy back from the antenna circuit to the oscillating circuit, which would cause losses.

33. The antenna current reaches its highest point on the wave to the right of *a*, view (*d*), Fig. 10. This current is now free to oscillate at the natural frequency of the antenna as determined by its electrical properties. From *a* the current decreases to point *b*, due to the radiation of energy into the ether and to losses in the antenna system caused by the resistance of the antenna. If properly designed, the resistance of the antenna should be quite low, and the losses from this source will be low. It is an established fact that all the energy cannot be radiated instantly; in fact, it is desirable that the radiation be prolonged over several cycles. If radiation were extremely rapid, the emitted wave would be broad and considerable interference would be produced. By using a feebly damped wave, however, such as the curve in view (*d*), very sharp tuning may be obtained and interference with neighboring stations is reduced. For this reason, the United States Government has specified that no sending station may operate

with a highly damped wave. The minimum number of cycles allowed per wave-train is 23, as shown by the complete waves between *a* and *b*, view (*d*). In order to be within the law, most stations use a larger number of waves to a train than required by the government.

In order to determine the location of point *b*, view (*d*), it is necessary to establish a certain relation between the height of the wave at the maximum point and the height of the wave at a point where the wave-train is practically damped out. In practical work this is considered to be the point at which the amplitude of a wave is $\frac{1}{100}$ part of that of the wave at the maximum point. The number of waves in a train of this kind is very difficult to determine and there is seldom need of knowing it in practical work, as long as the conditions comply with government regulations.

RECEIVING

REASON FOR USING SPECIAL APPARATUS

34. Radio signals travel from the sending station equally well in all directions, except for the directional effect of some types of antennas, and the interference of conducting substances. The waves are able to follow the gradual curvature of the earth quite readily, but cannot easily adapt themselves to the rough outlines of intervening high hills and mountains. The presence of such obstacles between stations will seriously interfere with communication, particularly if they are near either of the stations. In most cases, the amount of energy radiated into space is not exceptionally large and only a fractional part of this energy can be collected at any distant point. The ever decreasing wave necessitates the use of a sensitive receiving device, particularly when the stations are some thousands of miles apart.

35. For this purpose an antenna system is erected in a favorable location to intercept the high-frequency radio waves.

These waves induce currents in the aerial which are exactly similar to those emitted by the sending station, although they are necessarily of much smaller amplitude. The receiving antenna should be tuned to the same wave-length as that of the radio signals which are to be received, because the strength of the induced current will be larger when the natural period of the receiving antenna system is the same as that of the sending antenna. So important is this fact, that it is usually impossible to receive any signals unless these circuits are properly tuned.

METHODS OF RENDERING THE INTERCEPTED SIGNALS INTELLIGIBLE

CURRENT-INDICATING DEVICE IN THE ANTENNA

36. Expansion-Type Ammeter.—When the high-frequency signals are intercepted by the antenna system, some means must be provided for rendering them intelligible to some one of our senses. Perhaps the simplest method of doing this is by conducting them through a current-indicating device, such as an expansion-type ammeter, represented at *a* in Fig. 11. The incoming groups of wave-trains will cause the needle to be deflected, and the length of time during which the indication is made will correspond with the dots and dashes of the telegraph code. The expansion-type ammeter is very slow-acting; therefore, it is not entirely satisfactory as a signal indicator. The amount of energy received by an antenna is very small, and a system using such an indicator could be employed only for very short distances. Other sensitive current-indicating devices may be used in place of an expansion-type ammeter.

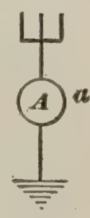


Fig. 11

Fig. 12

37. Detector and Telephone Receivers.—A method giving greater speed in receiving than can be had by use of the ammeter is shown in Fig. 12. The expansion-type ammeter used in the previously described method is replaced by a

detector *a* and telephone receivers *b*, connected in series in the antenna circuit. As has been explained, the detector readily permits the passage of current in one direction and prevents current in the opposite direction. If it were not for the detector, no sound would be produced by the high-frequency alternating current in the telephone receivers. This may be explained as follows: The radio-frequency alternating current in the electromagnet windings of the receiver attracts the diaphragm, first in one direction and then in the other so rapidly that the diaphragm cannot respond to give audible sounds. The several rectified impulses in one wave-train, however, act upon the diaphragm successively in one direction, and combine to produce one vibration or movement of the diaphragm resulting in a click. A series of these clicks, due to successive wave-trains, follow each other in rapid succession, producing a note in the receiver. The dots and dashes of the telegraph code may thus be produced; a short series of clicks represents a dot, while a longer series represents a dash. With the arrangement shown, the resistance of the telephone receivers must be kept low, so as not to limit the current unnecessarily.

38. The discussion of coupled circuits emphasized the fact that the energy transferred from one circuit to the other is at a maximum value when these circuits are tuned the same, that is, when their natural wave-lengths are the same. This rule holds true whether the circuits are adjacent to each other or are thousands of miles apart. So important is this consideration, that communication is possible over distances several times as great when the circuits are properly tuned as when no attempt is made to attain this desirable condition. No provision for tuning was made in either of the systems indicated in Figs. 11 and 12. The natural wave-length of the antenna system in each case is fixed and depends upon the electrical characteristics of its circuit. Such an arrangement is very inefficient as a receiver, even when the stations are relatively close together. Reception is also difficult, due to interference from signals on other wave-lengths, as no provision is made

for changing the wave-length of the antenna so as to tune out the undesirable signals.

39. Set With Tuned Antenna.—The capacity of an antenna is usually quite large, while its inductance may be rather small. A very considerable change of wave-length may be made by placing a variable inductance coil in the antenna circuit, thus permitting accurate adjustments of the wave-length of the antenna in order to obtain sharper tuning. Such an arrangement is shown in Fig. 13, with the variable inductance coil *a*, the detector *b*, and telephone receivers *c* all connected in series between the aerial and the ground. The action of the detector is identical with that of the detectors previously described. A click is produced in the receiver for every high-frequency wave-train. Introducing a condenser between the inductance coil and the detector renders the tuning sharper, and also decreases the length of the radio wave which may be received satisfactorily. The chief advantage of the tuned antenna lies in the fact that its natural period of vibration may be changed to correspond with that of the sending antenna. Under this condition, the current established in the receiving antenna is maximum, and the received signals will be clearer.

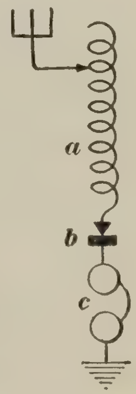


FIG. 13

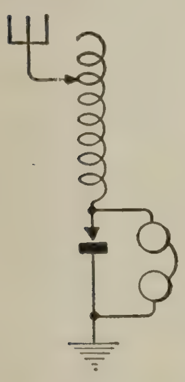


FIG. 14

40. In order that the strength of the received signals may be as great as possible, it is desirable that the resistance of the antenna circuit be kept low. Fig. 14 shows the telephone receivers connected in parallel with the detector; this reduces the resistance of the antenna circuit from what it was with the series arrangement of detector and receivers shown in Fig. 13. Not much improvement in the tuning qualities of the antenna circuit is accomplished by the parallel arrangement.

The action of the receiving apparatus may be explained as follows: The wave-trains from the sending station tend to establish an alternating current in the wires of the antenna

and its connections. Current can pass through the detector only in one direction due to its uni-directional feature. Very little current at radio frequency can pass through the telephone receivers because of their high impedance. Assume that the detector is so connected that the current passes from the earth upwards through the crystal detector to the antenna, but the return current is practically blocked. The rectified oscillations accumulate, therefore, in the form of a charge on the antenna wires. When this charge is sufficiently high, the antenna discharges through the receivers to the ground, producing a single click for one wave-train and a signal for a series of trains.

DIRECTLY COUPLED RECEIVING SETS

41. Definition.—Receiving sets that use an autotransformer to form the coupling between the primary and the secondary circuits are said to be *direct coupled*. The autotransformer is essentially an inductance coil with one common terminal and two movable contact points, one for the primary and the other for the secondary circuit. This type of coupling, shown in Figs. 15 to 18, inclusive, has the advantages of simplicity and cheapness.

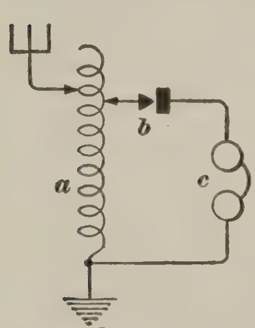


Fig. 15

42. Detector and Telephone Receiver in Series in the Secondary Circuit.—The resistance of a detector is usually quite high, as is also that of the telephone receivers. An arrangement in which both these devices are removed from the antenna circuit and transferred to a shunt circuit is indicated in Fig. 15. The inductance coil *a* is the only device connected between the antenna and ground; the series arrangement of the detector *b* and the telephone receivers *c* is in parallel with a portion of the inductance coil. For clearness of explanation the antenna circuit may be called the primary, and the circuit consisting of the detector, telephone receivers, and part of the autotransformer, the secondary.

The rectifying action of the detector converts the incoming radio-frequency alternating current into a pulsating current capable of energizing the telephone receivers to produce sound signals. A movable contact on the coil permits tuning of the natural wave-length of the primary to that of the incoming wave. A similar contact in the secondary circuit provides a means for tuning its circuit to that same wave-length. This principle corresponds exactly with that used in the sending station in which, as previously explained, the energy transfer from one circuit to another is found to be greatest when the two circuits are tuned to the same wave-length.

43. Detectors and Telephone Receivers in Parallel in the Secondary Circuit.—In Fig. 16, the detector *a* and the telephone receivers *b* are connected in parallel across a portion of the inductance coil. The action is to a certain extent similar to that in the set shown in Fig. 14. During the period of a cycle when the current at radio frequency passes from the antenna to the ground, Fig. 16, comparatively little of this current can pass through the detector because of its unidirectional feature, or through the receivers because of their very considerable impedance to the passage of a high-frequency current. Most of the current, therefore, will pass through the inductance coil. During the alternate half-cycle, current can readily pass from the ground to the antenna through the detector. As these half-waves of current are stronger than the other half-waves, the antenna system will accumulate a charge of a given polarity, and, when the charge is of sufficient value, the antenna will discharge a current through the receivers, thus producing a click. Figs. 15 and 16 represent the simplest receiving circuit connections and the least number of devices that may be used to receive damped-wave radio signals satisfactorily.

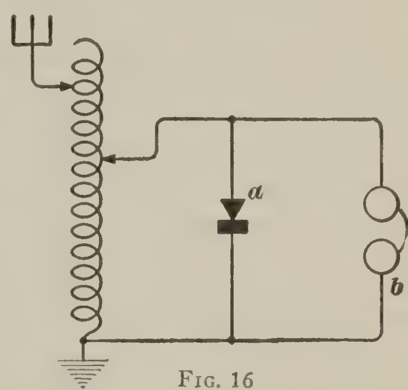


Fig. 16

44. Tuned Oscillating Circuit.—Better adjustments of the set may be secured by connecting a variable condenser *a*, Fig. 17, in parallel with the portion of the autotransformer that is used as a secondary. The set may then be tuned with greater accuracy and thus better selectivity may be obtained. The antenna and primary circuit are tuned to the wave-length of the incoming high-frequency currents. The closed oscillating circuit consisting of the secondary coil and the condenser may be adjusted for both inductance and capacity; therefore, the secondary circuit may be tuned to the wave-length of the primary. With suitable adjustments the oscillations in the secondary may be made to have considerable amplitude, thus producing a high impressed voltage on the condenser. Part of the energy of the secondary oscillating circuit affects the shunt detector circuit and the current is rectified by the crystal detector in order to produce a sound in the receivers.

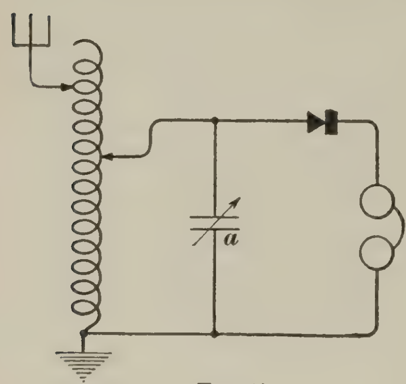


Fig. 17

45. Telephone Receivers Shunted by a Condenser. The sound in the telephone receivers is frequently improved by shunting them with a condenser, as represented at *a* in Fig. 18. A fixed condenser of small capacity will serve this purpose. In all other respects this circuit is similar to that in Fig. 17. This addition could be applied to the arrangement shown in Fig. 16 with good results. During the period when electricity flows through the detector, Fig. 18, the voltage is applied across the telephone receivers, and also across the condenser in parallel with them.

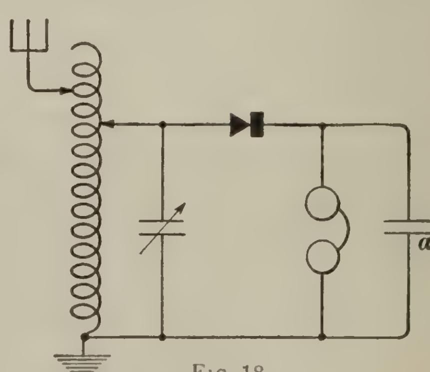


Fig. 18

The short interval between the rectified half-waves of the high-frequency incoming signals is thus smoothed over by the condenser, which gives up to the receivers energy received during the previous half-wave pulsation. The action of the receivers is thereby strengthened.

The receiver leads, as used in practical work, consist of two long conductors bound quite close together by an insulating covering. The wires in the leads thus give a condenser effect in parallel with the receivers and by their natural action in some cases possess sufficient capacity to obviate the necessity for using a special or separate condenser. In many instances an apparent advantage is gained by making the shunt condenser variable, although this is not always true.

INDUCTIVELY COUPLED RECEIVING SET

46. An **inductively coupled receiving set** makes use of separate coils in the antenna and oscillating circuits, the action being quite similar to that which has been described relating to the transfer of energy from one circuit to another by induction. The use of such an arrangement is illustrated in Fig. 19, in which the two inductance coils *a* and *b* form simply the primary and secondary, respectively, of an air-core receiving transformer. In all other respects this arrangement of circuits and apparatus is identical with that of Fig. 18.

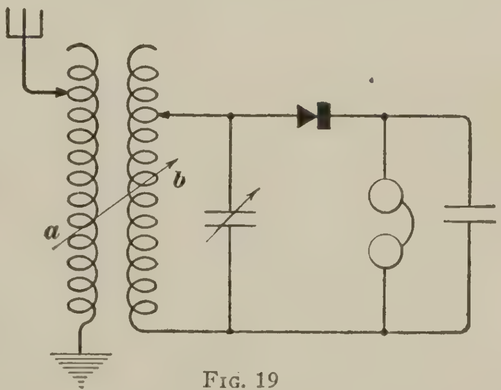


Fig. 19

As ordinarily constructed, one or both of the coils, Fig. 19, are mounted on movable supports and their relative positions may be changed as desired. A very important advantage of this type of mounting is the coupling adjustment provided. The preliminary tuning is often made with the coupling between the coils very close, as in that condition the receiving set will

respond to any radio waves whose wave-length is approximately that of the tuned wave-length. As soon, however, as the desired station is heard, the coupling between the inductance coils is made looser, but not to such an extent as to cause the signals to be very weak. The set is then finally and accurately tuned for the new coupling conditions. This will probably cause the strength of the received signals to decrease from their original strength, but the elimination or tuning out of undesirable stations in many cases renders this procedure highly desirable.

Many experiments and trials indicate that the interference caused by static may be very materially reduced by using loose coupling. In many instances decided relief has been obtained by this means; the received signals coming in very clear after applying this remedy.

47. The various types of receiving transformers that may be used have been described in considerable detail in a preceding Section. Many of them are particularly adapted to close coupling work, while others permit of very loose coupling between the two windings. The advent of coils wound with several layers of wire makes the coils much shorter and is really responsible for the practice of loose coupling. This system is especially applicable to honeycomb wound coils; it is entirely feasible in many cases to use a coupling length of 6 to 8 inches between the coils, while satisfactory reception has been obtained with the coils separated as far as 18 inches. For this unusual receiving work, the conditions must be exceptionally good. As long as enough lines of force from the primary cut the secondary coil to induce audible signals, the operation will be satisfactory.

TUNING THE ANTENNA CIRCUIT

48. Methods for adapting the circuit of Fig. 19 to the reception of either very long or very short radio waves are indicated in Fig. 20. The primary winding *a* is the one effective in transferring energy to the secondary coil in the oscil-

lating circuit. The primary coil possesses a large inductance. The addition of a so-called *loading coil b,* which is merely a variable inductance coil, serves to increase the natural wave-length of the antenna, the change produced being directly dependent upon the amount of inductance actually in use. The natural wave-length of the antenna may also be increased by the use of a variable condenser *c* connected in parallel with whatever inductance may be used, as represented by the dotted lines in Fig. 20. A variable condenser of small capacity is sometimes used in this manner to provide a means for making very fine and accurate adjustments of tuning of the antenna system.

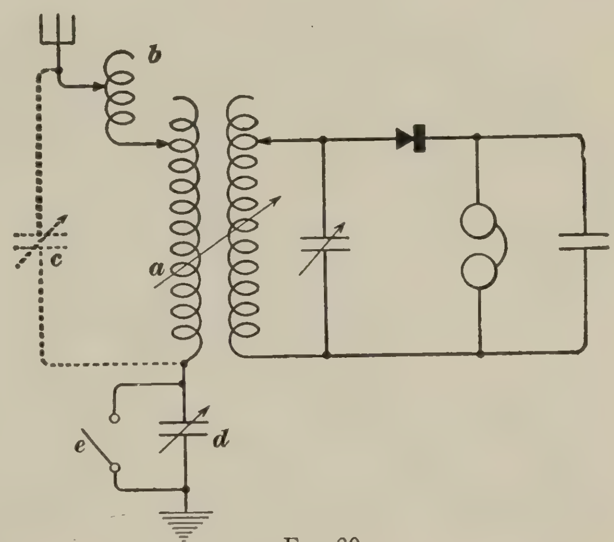


FIG. 20

49. For decreasing the natural wave-length of an antenna system, a variable condenser is usually connected in series in the antenna circuit as shown at *d,* Fig. 20. A short-circuiting switch *e* is normally closed when the condenser *d* is not required, the condenser then producing no effect on the wave-length. When an antenna is constructed, it is so designed that its natural wave-length will be near that on which the most of its intended radio communication will be conducted. One of the means described above is then used to secure any other necessary wave-lengths. The use of auxiliary devices is objectionable, in that additional losses are introduced into the receiving set with a consequent decrease in the strength of the signals received. Such apparatus, however, is often necessary, as it provides a simple and effective means for securing a desired wave-length beyond the range possible with a particular set. The use of condensers and inductance coils to modify the natu-

ral wave-length of an antenna is limited; it is not practical to add sufficient inductance to more than double the natural wave-length, nor to use a series condenser that will decrease the natural wave-length by more than one-half. These methods, within limits, may be applied to any type of receiving antenna system with equal success. The changes described are applied only when necessary, and when the range of the set is not exceeded; that is, it would be futile to change the antenna's wave-length to respond to signals that the receiving set could not handle.

ELECTROSTATICALLY-COUPLED RECEIVING SET

50. A circuit employing **electrostatic coupling,** or coupling through condensers, is represented in Fig. 21. The two condensers *a* and *b* are known as *coupling condensers.* Coils *c* and *d* are so placed that the lines of force of one coil do not interlink the other coil, hence they do not furnish any coupling; they are used solely to change the inductance of their respective circuits. The only change of coupling between the antenna and oscillating circuits is that afforded by varying the two condensers *a* and *b,* which are usually mounted on one shaft, thus rotating together to produce equal capacity changes. It is claimed that this circuit arrangement affords very good reception of signals and the coupling adjustments may be made easily and rapidly.

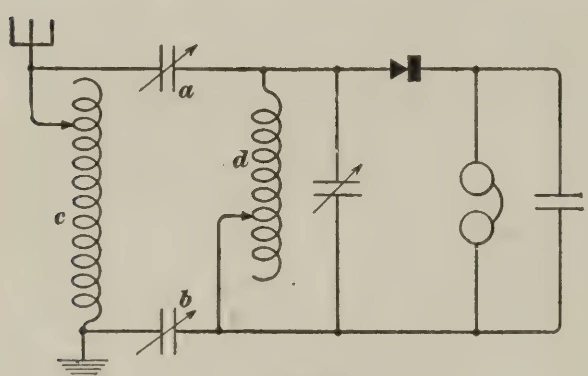


Fig. 21

51. An electrostatically-coupled receiver, which is very simple both in circuit arrangement and operation, is shown in Fig. 22. If the coupling condensers *a* and *b* are of medium capacity they need not be variable, and the only adjustment will be that provided by the inductance coil. Extreme sim-

plicity is thus secured, but partly at the expense of selectivity, the receiving set having a tendency to respond to a wide variety of wave-lengths. It is customary to make the two condensers *a* and *b* of the same capacity, but if *b* is made somewhat larger than *a* an extra condenser, as indicated at *c*, may be eliminated. This circuit arrangement with only one tuning adjustment is particularly useful where quick tuning is required and only small interference is likely to be encountered.

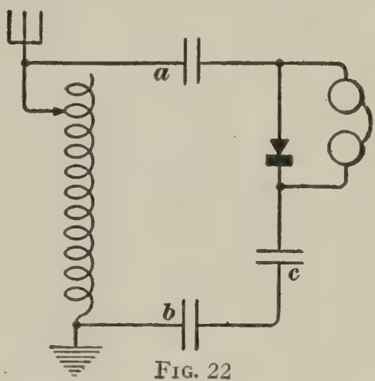


FIG. 22

OTHER POSSIBLE ARRANGEMENTS

52. Many other circuit arrangements than those just described are possible, some extremely simple, and others needlessly complicated. The receiving sets put up by different manufacturers naturally differ largely as to the arrangement of apparatus, the adjustments provided, and as to the number and quality of the component devices.

The particular receiving set to use in any case depends, to a very large extent, upon the purpose for which the station is to be used. If long-distance receiving is to be attempted, the currents handled will be very minute and the receiving set must be exceptionally well designed and assembled. In many cases one type of receiving circuit may work very well on one particular antenna system, while if used on some other one, satisfactory reception may be impossible. This is usually considered to be due to characteristics of the antenna rather than to faults in the set itself. In any case, whether reception is good or poor, it is advisable to try various arrangements and electrical connections of the apparatus with a view of obtaining the most satisfactory arrangement possible with the given equipment. Circuits radically different from those illustrated may be found that will give excellent signals with a particular or special type of aerial.

TUNING A RECEIVING SET

53. The great variety of receiving sets makes it difficult to formulate definite rules for tuning and for operation that will apply in all cases. Instructions are generally furnished by the manufacturer relating to the operation of the set supplied, and these should be followed to obtain good results.

54. The following suggestions apply in many cases, but the operator should modify these to suit his apparatus and the operating conditions. The set illustrated by Fig. 19 is to be considered and it is desired to tune the apparatus so as to receive signals from some particular station.

If the wave-length of the sending station is known and the proper setting of the receiving set for that wave-length has been ascertained, the problem is very much simplified, as the setting may be made direct. A small adjustment, particularly of the coupling, while signals are being received may help to make them more clear.

If the approximate setting is not known, the two inductance windings should first be coupled closely, as then the set will respond to radio waves even if not tuned to the exact wave-length of the station sending the message that is to be received. Arbitrary settings of the primary inductance are then made and the secondary inductance and capacity are slowly varied over the range of their scales. In many cases in which accurate tuning is required, a very small variation of any of the settings will throw the set out of tune, and cause the signals of the sending station to be lost. It is, therefore, important that the adjustments be made gradually, and not so fast that the correct point may be passed over unawares.

Sometimes two separate settings of the receiving set will give clear signals. This usually indicates that the energy from the sending station is being emitted on two distinct wave-lengths. This condition cannot be remedied at the receiving station; but it is necessary to select the wave-length that gives the clearest signals.

SETTING THE DETECTOR

55. For the best reception of radio signals, it is important that the detector be set on a sensitive point. If signals can be easily tuned in from the antenna, the detector may be adjusted from point to point until a satisfactory response is given. In many cases, however, no response can be obtained until the detector is on a sensitive spot even if the remainder of the receiving set is perfectly tuned. This is particularly true of weak signals from remote stations. If the detector point is set in a haphazard way by guesswork, considerable time may be lost in trying to pick up or tune in a station with the detector improperly set, or perhaps not even working.

56. A method of energizing the antenna for the purpose of testing the detector is indicated in Fig. 23. A circuit including a small buzzer *a* operated by a battery *b* is loosely coupled with the antenna system by means of coils *c* and *d*. When key *e* is closed, the buzzer produces a pulsating current in coil *c* and by induction an alternating current is established in coil *d* and in the antenna circuit. A small current will then be established in the receiving circuit by induction from the antenna circuit. The position of the detector point is changed several times until the sound produced by the buzzer comes in clear and strong. The setting of the detector is then on a sensitive spot, which will also respond to radio signals, and the usual tuning may be completed. As soon as a good point on the detector is found, the buzzer is stopped by opening its circuit at *e*, as its continued operation would only produce interference.

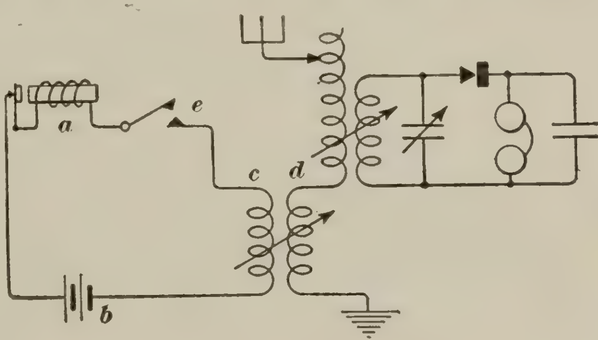


Fig. 23

SHAPE OF CURRENT WAVES

57. Fig. 24 shows, with approximate accuracy, the forms of the current waves in the parts of the receiving set. In practice, there is considerable variation in the form of these waves. Only a few waves per train of the antenna current are indicated in view (*a*). There are actually many more, their number depending upon the kind of wave intercepted by the aerial and, to a limited extent, on the characteristics of the receiving set. A little time is required for the current in the antenna to reach maximum value; therefore, the first two cycles are shown as of less amplitude than the ones immediately following them. The radio-frequency oscillations are now transferred from the antenna circuit to the oscillating circuit, Fig. 19, by induction.

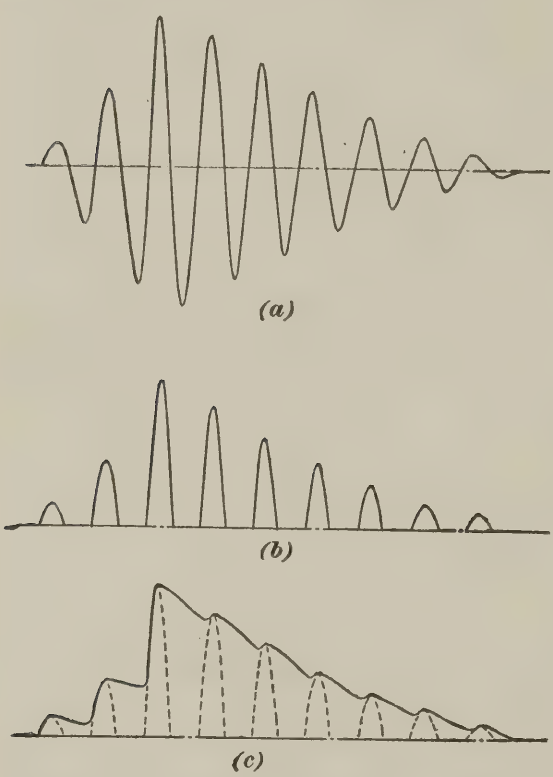


FIG 24

58. Voltage wave-trains of the general form shown in Fig. 24 (*a*) are impressed on the circuit containing the detector and the telephone receivers, Fig. 19. The detector offers very high resistance to the passage of current in one direction and low resistance to the passage of current in the other direction. Unidirectional current impulses, Fig. 24 (*b*), are, therefore, established in the telephone circuit by the alternating voltages induced in the secondary coil *b*, Fig. 19. Because of the rapidity of the impulses, the diaphragm cannot vibrate in unison, but the

effect of a group of impulses is to attract the diaphragm toward its magnet and to release the diaphragm when the impulses cease. The diaphragm produces a click for each train of waves, and a musical tone for a series of trains.

The condenser that shunts the telephone receivers is charged during the intervals of time that electricity flows through the detector, and discharges a current through the receivers during the intervals when the detector blocks a flow of electricity. The action of the condenser causes the forces acting on the receiver diaphragms to be more nearly continuous and thus improves the tone of the receivers. The curve represented as a heavy solid line in Fig. 24 (*c*) indicates approximately the rise and fall of the current in the receivers for each incoming wave-train. The peaks of the curve are due to the impulses of current direct from the detector. The portion of the curve between the peaks represents the current supplied to the receivers by the discharge of the condenser. The dotted curves are used merely to indicate how the solid-line curve is derived from view (*b*).

In Fig. 24, the upper part of the wave-train, that is, the part above the horizontal axis, is indicated as the part affecting the receivers; the lower part of the wave-train could, however, be used. The portion that is effective depends on the manner of connecting the detector in its circuit; it is not important which part of the wave is used.

WAVEMETERS

DEFINITION AND USES

59. A **wavemeter** is a device for measuring the length of a wave in a radio circuit. Reference has been made to the importance of having coupled circuits accurately tuned to the same wave-length, and to the necessity of having transmitting and receiving antenna oscillating at the desired wave-length. A wavemeter provides an accurate and convenient method for determining the length of a radio-current wave in a circuit, and for determining when a circuit is oscillating at the desired wave-length. For these reasons, it is one of the most important devices used in radio measurements.

MEASURING WAVE-LENGTH

60. Wavemeter Connections.—A wavemeter consists essentially of an oscillatory circuit containing a condenser and an inductance coil, connected in series, and some form of current-indicating device. Changing either the capacity or inductance will change the natural wave-length of the circuit of the wavemeter, but as the condenser is uniformly variable, that device is the one by which the wave-length is usually adjusted. The sensitive current-measuring or current-indicating device is either placed directly in the wavemeter circuit or is coupled to it. Fig. 25 illustrates such an arrangement with the current-indicating device *a* connected in series with the inductance coil *b* and condenser *c*. A suitable current-indicating device could be a small electric-light bulb, the kind used in flashlights being entirely satisfactory. The light will

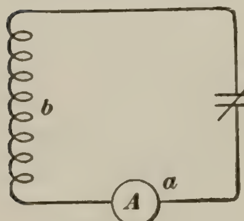


Fig. 25

glow at its maximum brightness when the natural wave-length of the circuit corresponds with that of the sending circuit, this condition indicating resonance between the two circuits. An expansion-type ammeter connected in series in the circuit, or a thermocouple with an ammeter as its current-indicating device is in more common use than a lamp, particularly in case the current indications are weak.

61. In the operation of this type of wavemeter the inductance coil *b* is placed so that its turns of wire are close to an inductance coil in the circuit under test. Lines of force from the excited coil energize the wavemeter coil and establish a current therein. This current also passes through the condenser and current-indicating device and the capacity of the condenser is adjusted until the current is observed to be a maximum. The condenser is customarily equipped with a scale, giving readings of wave-length in meters (1 meter = 39.37 inches), as this unit has come into universal use for expressing wave-lengths. This scale must be calibrated, or its readings checked with the actual devices with which it is to be used, and will then give accurate measurements. A setting should finally be secured so that further turning of the condenser handle in either direction of rotation, so as to vary the capacity even slightly, will cause a *decrease* in the current. If no such position can be found, but instead, a considerable range of capacity adjustment gives a large current indication, the coupling between the inductance coil of the wavemeter and the inductance coil of the circuit under test should be decreased until one clearly defined reading is obtained.

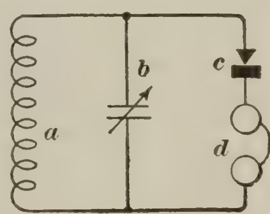


FIG. 26

62. When the received energy is very small, a circuit arrangement, as shown in Fig. 26, is usually preferred. The inductance coil *a* and the variable condenser *b* are connected in series and the oscillating circuit thus formed offers a low resistance to the passage of the induced current. Sounds are produced in the receivers in a manner similar to that which has been described in connection with receiving sets. Reso-

nance between the circuit under measurement and the wavemeter is determined by the maximum strength of signal produced in the telephone receivers. By the use of telephone receivers, indications of very weak waves may be read accurately. A great advantage of this set is that it is very rugged, there being no sensitive current-measuring instruments to be injured by rough handling.

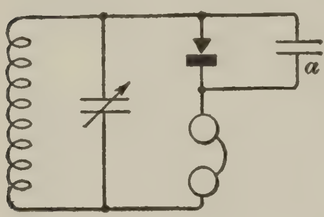


Fig. 27

63. The addition of a fixed condenser shunting the detector will in some cases give stronger signals than would otherwise be obtained. Such a circuit is represented by Fig. 27, the addition of the fixed condenser *a* being the only difference between this figure and the preceding one.

64. As the resistance of many current-indicating devices, which may be used, is often rather high, it is occasionally desirable that they be removed from the oscillating circuit. This may be accomplished, as shown in Fig. 28, by connecting the primary coil *a* of a small oscillation transformer in the oscillating circuit. The current-measuring or indicating device *b* would then be connected across the secondary terminals *c* of the oscillation transformer. The coupling between these two circuits should be as loose as possible consistent with the production of a good value of current in the secondary circuit. No particular advantage is gained by placing the combination of a crystal detector and telephone receivers in a local coupled circuit; in fact, with such arrangement the operation is apt to be much poorer than when they are connected as has been shown in Figs. 26 and 27.

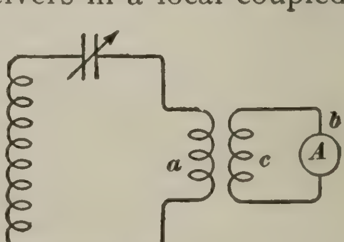


Fig. 28

The range of a wavemeter may be enlarged by using coils of different values of inductance. The condenser must then be furnished with scales which will give a true reading of wave-length with the particular coil in use. Practically the same results would be obtained by using condensers of different sizes, but this method has not been used in prac-

tice. Using a coil with a larger inductance raises the value of the wave-length readings by an appreciable amount. Similarly, decreasing the inductance lowers the range of wave-lengths at which the wavemeter will give maximum-current indications.

65. Measuring the Natural Wave-Length of an Antenna.—In order to measure the natural wave-length of an antenna system without radiating a large amount of energy, a very simple arrangement, as shown in Fig. 29, may be used. A regular wavemeter circuit is excited by a small buzzer *a*, which in turn is operated by a battery *b*. A small push button *c*, or other type of switch, closes the buzzer circuit when so desired. Each current impulse through the buzzer circuit establishes a high-frequency current in the oscillating circuit connected to the buzzer circuit, whose wave-length depends upon the values of inductance and capacity in the oscillating circuit. By means of inductance coils, as *d* and *e*, this energy is transferred to the antenna and sets up a wave therein. If the induced wave is near the antenna's natural period, and the coupling is not too close, the length of the wave set up in the antenna will depend upon the inductance and capacity of the antenna. In case the natural wave-length of the antenna is desired, the inductance of coil *e* should be small so as not to change the characteristics of the antenna circuit when it is removed after completion of the testing. Coil *d* may be coupled directly to the antenna inductance *f*, instead of using an extra coil *e*, with the consequent liability of changing the natural wave-length of the antenna.

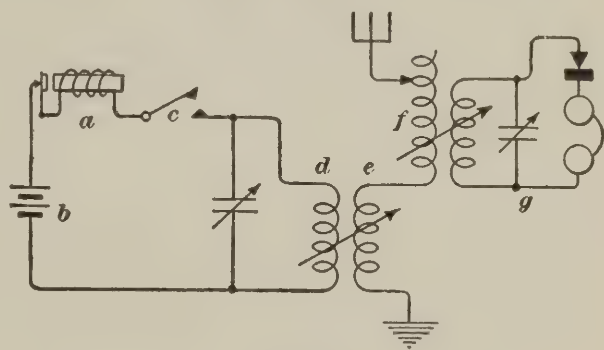


FIG. 29

If a wavemeter *g* is coupled to coil *f*, the length of the wave that is established in the antenna may be determined. To be

certain that the wave-length measured is that of the antenna, care should be taken that the wavemeter is placed near f and not near d.

66. Calculation of Wave-Length.—The natural wave-length of a vertical or flat-top antenna may be calculated, but with only rough approximation to accuracy, as follows:

Add the average height of the antenna to the horizontal length, both measured in feet. Multiply the sum by 4.2, and to get the natural wave-length, expressed in meters, divide the product by 3.3. In the case of the vertical-wire type of antenna, use the total height. This is the same as saying that the natural wave-length is slightly greater than the combined height and horizontal length of the antenna measured in meters.

The natural wave-length of a vertical-wire aerial is slightly less than the value obtained by the above rule, while the calculated value for the umbrella-type aerial and others having large tops is apt to be rather low.

In the **L** and **T** types of antennas of moderate sizes, the number of wires in the flat-top part is not very important unless they are widely spaced, say about 10 feet. When such large spacing is used, the natural wave-length is increased by the addition of wires to the flat-top part. Trees and buildings in the vicinity and especially below the antenna, tend to increase the wave-length to some extent. Results obtained by the above rules are not apt to be so accurate as those obtained by the use of a good wavemeter.

ELECTRON TUBES

ELEMENTARY PRINCIPLES

ELECTRON THEORY

1. The **electron tube** is one of the most important pieces of apparatus employed in radio communication, and its use has aided greatly in the development of radio telephony. There are several names applied to the electron tube, among them being *vacuum bulb, vacuum valve, vacuum tube,* and *audion.* These terms are often used interchangeably, and are due to the preferences of different writers and manufacturers, being in some cases descriptive, and in others, trade names. In general, the name electron tube will be used in this Section, since it implies the principle of operation of the device.

2. The operation of an electron tube is based on certain fundamental electrical considerations. **Electrons** are extremely minute particles of negative electricity, and represent the smallest known components of matter. An *atom* is the smallest part into which matter can be divided by chemical means. The atoms are extremely small, but are many thousands of times larger than electrons. Although electrons cannot be seen, their characteristics, such as size and weight, have been determined with at least approximate accuracy. Many phenomena may be explained by the application of the electron theory.

Electrons are negatively charged and are in constant motion around the remaining portion of the atom, sometimes called the *nucleus,* which normally has an equal but positive charge.

Under normal conditions the two opposite charges neutralize each other and the atom indicates no resultant charge. The atom may, then, be considered as being made up of a mass carrying a charge of positive electricity, around which rotate a number of smaller masses carrying charges of negative electricity. The general characteristics of atoms are different for different materials, but all electrons are identical in all respects, there being a larger number of them associated with some atoms than with others.

3. This phenomenon may be compared with that of our solar system. The nucleus of the atom may be compared with the sun, around which move the smaller bodies, such as the planets, which are influenced by the central mass and follow well-defined orbits. As in the solar system, most of the electrons, which may be compared with the planets, follow regular closed paths with no variation. There are some electrons, however, that follow quite eccentric and unusual paths, as do the comets of our solar system. These comets are not always influenced by one central system, but should they be acted on with sufficient force by some other system, they are apt to move from one system to another. Some electrons exhibit these characteristics and may move from atom to atom with changes in the forces acting on them.

DIRECTION OF FLOW OF ELECTRONS

4. An electric current in a conductor is believed to consist of a flow of electrons, each electron carrying a small charge, and the sum of all the charges representing the total current. One theory is that the electrons carry the charges from place to place by a migratory travel, while another theory suggests that charges on the electrons are discharged from one electron to another electron or to an atom with which it may collide, thus setting up a relay action. The electrons are thought to be influenced in their travel by the electromotive force producing the electron flow, and this transfer has been proved to be from a point of negative potential to a point of positive potential.

5. The direction of the flow of electrons is apparently in direct opposition to the assumed direction of the flow of electricity; that is, the current passes from a positively to a negatively charged body. This is purely an assumed direction, however, and was made before the direction of the flow of electrons was known. These two conditions must be kept separate, as it is still universal practice to consider an electric current as passing from a position of positive potential to one of negative potential, and the flow of electrons is known to be in just the *opposite* direction. It is entirely possible that the current is actually in the assumed direction, and not in the direction of the flow of electrons.

6. The rate of travel of the electrons, both in their fixed orbits and in their travel between atoms, is very rapid, and increases considerably with an increase of the temperature. This fact is one of particular importance in the study of electron tubes, and will be considered further in a succeeding paragraph. It is usually considered that certain characteristics of conductors are especially favorable to the passage of electrons, and that insulators oppose their motion to a large extent. There appear to be some electrons floating promiscuously in the space around atoms in a vacuum. The introduction of an electromotive force will cause these free electrons to take a certain direction of movement, that is, to be directional in their movement, many of them passing to the positive terminal, and this movement of electrons establishes an electric current.

EFFECT OF CHANGE OF TEMPERATURE ON THE FLOW OF ELECTRONS

7. The motion of the electrons around an atom becomes much more rapid with an increase in the temperature of the atom. These electrons may become agitated to a degree sufficient to cause them to fly off from the parent atom, much as minute particles of water are freed by the violent agitation of boiling water to form steam. The loss of the negative electron will leave the nucleus of the atom with a positive charge. If

the electron which freed itself from the atom does not fall under the influence of another positive charge, it is probable that it will find its way back to its parent atom. Investigation of the space surrounding materials emitting electrons has disclosed the fact that, while there may be many electrons given off, very few of them reach an appreciable fraction of an inch from the atom. It seems highly probable that the positive charge on the nucleus of the atom exerts some influence on the electron even after it has left the immediate vicinity of the atom. If the freed electron does not return to its parent atom, it will travel around promiscuously until it falls into the field of some other atom and attaches itself thereto. If several electrons should leave an atom, it is highly probable that the positive charge remaining on the atom would be high enough to draw some of the freed electrons back into its immediate vicinity, or at least prevent the withdrawal of any more electrons. The original atom would continue in its positively charged condition without a full number of electrons until it would be able to collect other negative charges which might accidentally come into its field. It may be that the emission of electrons changes the nature of the atom to some extent, and that an atom of any one kind of material controls or has attached to it a definite number of electrons.

FLOW OF ELECTRONS IN A VACUUM

8. As the conditions met with in radio practice deal with the flow of electrons in a vacuum, this condition will be considered in studying the flow from a heated body. It is extremely difficult to secure an absolute vacuum, that is, one entirely devoid of free atoms and electrons; but it is entirely possible to obtain a condition where there are very few. If there is such a good vacuum that there is a scarcity of electrons, some must be produced and released before there will be an appreciable flow of electrons and consequently the establishment of an electric current.

A closed glass tube is a common and satisfactory container inside of which a vacuum may be produced. If then a wire

is placed so that part of it extends inside of the tube and part outside, the whole wire may be heated by applying a candle or some other heating device to the part outside of the tube. When the wire is heated, electrons will be given off all along its length, the number depending upon the temperature of the wire.

This is a very inefficient way of heating the portion of the wire inside the tube. A more satisfactory method is to form the wire into a loop, place it inside the tube, and bring both ends out through the glass walls. If an electric current is passed through the loop, the wire will become heated very much as does the filament of a common incandescent lamp, but as there are no controlling or influencing forces acting on the emitted electrons, they will shoot out in all directions from the heated wire, or filament.

TWO-ELEMENT ELECTRON TUBE

ELEMENTARY TYPE

9. Another wire placed partly inside and partly outside of the tube containing the heated filament, previously mentioned, will collect some of the electrons that collide with it, and a sensitive current-indicating device, connected between the filament and the wire, will show that a flow of electricity is taking place. As the number of electrons emitted depends upon the temperature of the filament, the current will also depend upon the same factor. Under these conditions the electrons are radiated in every direction, and consequently those coming in contact with the additional wire represent only a small part of the total number liberated in the tube.

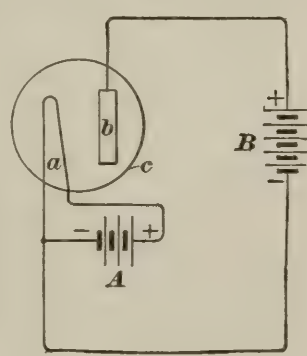


Fig. 1

10. Increasing the area of the active surface of the wire element by attaching a small metal plate to its interior end,

will cause the element to intercept more of the electrons and thus a larger current will be established. Fig. 1 represents this condition with the filament at *a*, and the metal plate at *b*. The glass containing tube or bulb is represented by the circle *c*, which is used in this connection in many succeeding illustrations as a conventional representation. The battery *A* supplies current for heating the filament. The battery *B* serves to establish an electromotive force between the plate and the filament. In radio practice these batteries are commonly called the *A* and *B* batteries, respectively, and this system of designating them will be employed.

EFFECT OF BATTERY ON PLATE CIRCUIT

METHODS OF APPLYING VOLTAGE

11. The plate is connected to the positive terminal of the *B* battery, Fig. 1, and a higher voltage is impressed on the plate and filament than on the filament alone. This causes the plate to be positive with relation to the filament, and the plate, therefore, exerts a considerable electrical attraction on the electrons radiated by the heated filament. Under these conditions, the flow of electrons is highly directional and nearly all of them are gathered by the positively charged plate. The electrons in their movement carry small electrical charges from the filament to the plate, thereby causing a transfer of electrical energy, and a current will be established due to the voltage set up by the *B* battery, Fig. 1. To distinguish it from the heating current in the filament, the current established by the *B* battery in the plate circuit is commonly called the plate current.

To obtain a flow of electrons when no *B* battery is used, it is necessary to connect the wire from the plate to the positive terminal of the *A* battery. The plate is then at a slightly higher voltage, or potential, than that of most of the filament, and some of the freed electrons will be collected by the positively charged plate, causing a small current. If the wire were connected to the negative terminal of the *A* battery, the plate would be at a relatively lower potential than the filament, and

the electrons would have no tendency to collect on the plate. In fact, due to the law that like charges repel, the negatively charged plate will tend to prevent any settling of electrons on its surface.

CHARGE ON THE FILAMENT

12. Connecting the plate to the positive terminal of the *A* battery does not produce a large current, and a *B* battery is always used in practice. If the terminals of the *B* battery are reversed from the connections shown in Fig. 1, no current will be established, since the plate will then be negative with respect to the filament and the negatively charged plate will not attract the electrons. In fact, the electrons, being negative, will be repelled from the negatively charged plate, and as no electrons will be moving between the filament and the plate, there will be no current. This feature, namely, that a flow of electricity can pass only in one direction, that is, between the plate and the filament within the tube, is a very important one, and will be considered further.

13. The total number of electrons given off by the heated filament, it being assumed temporarily that no plate electromotive force is being exerted, will depend to a very large extent upon the temperature of the filament. The material of which the filament is manufactured will also affect the number of electrons emitted. Coating the filament with certain chemicals has been found to increase the production of electrons or at least assist their emission into the surrounding space.

The atom or body from which the electrons were emitted will have a positive charge remaining on it, and this charge will tend to draw the negative electrons back under its influence. The large number of freed electrons will also produce a negatively charged field surrounding the parent body which will exert a certain influence on additional electrons which may try to leave or enter. A point of equilibrium is reached at which the electrical phenomena balance and only enough electrons pass out to fill the places vacated by the ones passing on.

THE PLATE VOLTAGE AND FILAMENT TEMPERATURE

14. Consider the case in which the voltage of the *B* battery, Fig. 1, is impressed on the plate and filament. The temperature of the filament is maintained at a constant value by current from battery *A*. With a certain voltage applied to the plate and filament, there will be a definite number of electrons passing from the filament to the plate, and this number determines the value of the plate current. Not all the electrons produced by the filament, however, are attracted to the plate, as many of them continue to pass out into space promiscuously. If the voltage is increased, a value may be found at which practically all the electrons emitted by the filament are collected by the plate, and the plate current, as well as the flow of electrons, will be at a maximum. Increasing the voltage of the *B* battery to a still higher value is useless as the current cannot be further increased by this means, due to the limited number of available electrons. The maximum plate current established for a particular filament temperature or filament current is known as the *saturation current,* and is easily obtainable for any given conditions, a feature to be discussed later.

If the filament temperature is raised, more electrons will be freed and the plate current will be increased. Increasing further the plate voltage will now increase the plate current until another point of saturation is reached. The plate current actually depends on the transfer of electrons, and the number of electrons transferred is directly related to the voltage that is impressed by the battery on the plate and filament.

SPACE CHARGE

15. The electrons passing from the filament to the plate, Fig. 1, being negative, form a so-called *space charge,* which is a negative charge in the space between the filament and the plate. This space charge neutralizes, to a considerable extent, the effect of the positively charged plate, and is a factor directly responsible for limiting the number of electrons leaving the filament at any particular temperature.

The presence of a gas remaining in the tube means that there are atoms in the space between the filament and the plate. The electrons moving at a very high speed toward the plate may collide with these atoms, and the force may be sufficient to liberate some of the electrons accompanying the atom, and send the electrons on toward the plate. If these collisions occur with many atoms, the electron flow and the plate current will be increased an appreciable amount. The positively charged atom will now be attracted by the negative filament, and will travel toward it at a tremendous speed. In such a case, even with a small amount of gas in the tube, rather rapid deterioration of the filament occurs, and it is thought to be due to the numberless impacts of the rapidly moving positively charged parts of the atoms.

Another disadvantage of the tube with a poor vacuum is the erratic and unsteady action, due in a large part to the production of an electron flow independent of that controlled by the filament temperature and plate voltage. This auxiliary electron flow, being difficult or impossible to control, may be so great as to render the tube useless for some work. Electron tubes as made for power work at the present time have a very high degree of vacuum, and their operation is accordingly quite consistent and easily controlled. For some purposes, such as improved cooling, inert gases, as argon and helium, have been tried in small-power tubes. When these tubes are operated at a fairly low plate voltage, the electrons do not travel to the plate fast enough to break up the atoms with which they may collide, and the bad effects of gas mentioned above are largely eliminated.

CHARACTERISTIC CURVES

16. The way in which the plate current varies with changes in the plate voltage is indicated in Fig. 2, which shows characteristic plate-current curves for two values of current in the filament. During this test curve *a* was obtained by keeping the filament at a constant temperature. When the plate voltage was zero, that is, with no voltage applied, the plate current

was likewise zero, no electrons being attracted to the plate, and very few accidentally colliding with it. Increasing the plate voltage increases the flow of electrons to the plate with a result represented by the full-line curve *a*; distances to the right represent an increase in plate voltage, and distances upward correspond with increases in the plate current. The upper point, that is, where the curve takes a decided bend toward a horizontal direction, is known as the saturation point, and the corresponding current value as represented on the plate-current scale would be known as the *saturation current.*

17. The test to obtain the dotted-line, plate-current curve *b* is identical with that used to secure curve *a,* except that the filament is now heated to a higher temperature, and more electrons are being emitted. For any moderate value of plate voltage, the same plate current is produced in both cases, as is indicated by the coincidence of the lower portions of the two curves. The plate current now rises to a higher value, as represented by the dotted-line curve *b,* before its saturation value is reached, as the total number of available electrons has been increased. The higher saturation point is advantageous, as the larger range of plate-current values may be obtained by merely changing the plate voltage. Even with this arrangement a limit to the plate current will be reached, and the cuve *b* will soon become horizontal, showing that the current is then constant with an increasing plate voltage.

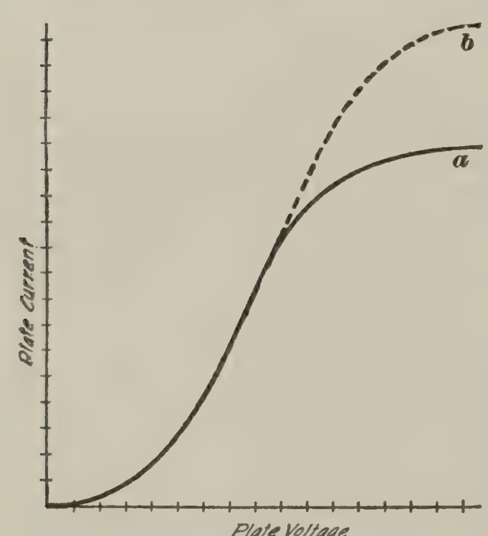


Fig. 2

APPLICATIONS OF THE TWO-ELEMENT TUBE

AS A DETECTOR

18. A radio receiving circuit using the two-element electron tube is shown in Fig. 3, the two elements being the filament *a* and the plate *b*. The current from battery *A*, which heats the filament, may be adjusted by means of the filament rheostat *c*, changes being made until the operation is most satisfactory. The remainder of the circuit represents a common radio receiving circuit, and differs only from a receiving set

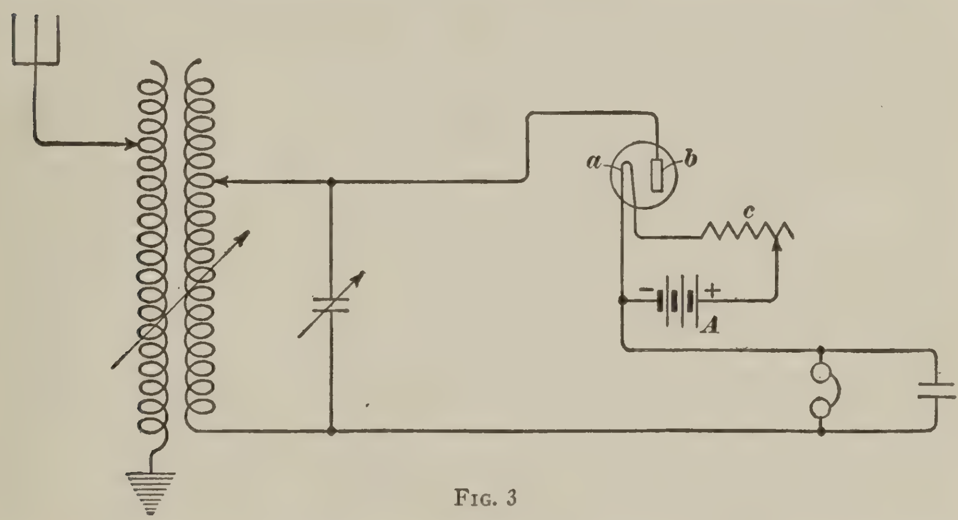


FIG. 3

using a crystal detector in that that device is replaced by the electron tube and its auxiliary apparatus. The electron tube, however, acts as a simple detector, and the operation is not unlike that obtained by the use of any other good detector. The fact that a flow of electricity can pass through the space between the plate and filament in only one direction, gives rise to its use as a detector in the reception of damped-wave radio signals.

19. In the circuit arrangement shown in Fig. 3 there is no *B* battery connected across the plate and filament, the voltage changes being due to the incoming signals collected by the antenna system and transferred to the oscillating circuit.

When a high-frequency wave-train is established across the plate circuit, the plate is made alternately positive and negative with respect to the filament. Therefore, a flow of electricity is established from the plate to the filament only during the brief time that the plate is positive. The telephone receivers being in series in this circuit are also energized by the rectified current, very much as they are with the other types of detectors.

OTHER USES

20. Another use of the two-element tube, and one of apparently increasing importance, is for the rectification of alternating current to direct current. The rectified current is not a smooth one, but is more of the nature of a pulsating direct current, which is suitable in such work as charging storage batteries. Some rectifiers are made for this work, using common 110-volt alternating current supply, while others are made, for other purposes, to operate satisfactorily from circuits having an electromotive force of several thousand volts. Tubes of this type have been used to some extent in voltage-control circuits. With given operating conditions, the plate current is constant, and cannot exceed a certain value depending upon the temperature of the filament. With an increase of the filament temperature, the plate current increases, as has been explained, this property being made use of in any desired manner.

THREE-ELEMENT ELECTRON TUBE

FUNDAMENTAL PRINCIPLES

EFFECT OF SPACE CHARGE

21. In the two-element electron tube the plate current depends largely upon the space-charge effect acting directly upon the flow of electrons. The space-charge effect limits the number of electrons flowing to the plate and thus the current from the plate to the filament, although the filament may be emitting more electrons than are used. A decrease in the space-charge effect will permit a larger electron flow and consequently a larger plate current will result, other conditions being favorable. Conversely, an increase in the effect of the space charge will decrease the current by limiting still further the flow of electrons. It should be remembered that the plate current may be increased in spite of the space-charge effect by raising the plate voltage, this increase being effective until a new balance is obtained between the space-charge effect and the plate voltage. The plate voltage may be made high enough so that fair operation may be obtained without hindrance by space-charge effect. A much more effective method for removing the space-charge effect, and one that also gives very good regulation of the electron flow, will be described in the next paragraph.

THIRD ELEMENT

22. For the three-element electron tube, the only change required in the two-element type is the addition of another element placed between the filament and plate, and consisting usually of a mesh or *grid* of fine wires, somewhat similar to a

window screen. Its resemblance to a grid causes that name to be applied to this element, although as actually made it varies considerably as to mechanical make-up. Normally, the flow of electrons passes through the rather large openings in the grid. However, some few electrons are bound to collide with the grid structure, but in any event, the current thus established between the grid and the filament will be very small compared with the plate current, and does not warrant further consideration.

EFFECT OF GRID BATTERY

23. Fig. 4 shows a three-element electron tube with its battery connections. The grid is indicated by the zigzag line between the filament and plate elements. The *A* and *B* batteries are shown connected according to common practice, and when a third battery is used, as here represented, it is usually designated as the *C* battery. An adjustable resistance and a double-pole, double-throw switch are connected in the circuit of the *C* battery. With a positive voltage applied to the grid with respect to the filament, the space-charge effect will be neutralized to an extent depending upon the amount of positive charge on the grid, and the flow of electrons and the plate current will increase until a new balance is obtained between the space charge, grid charge, and the flow of electrons.

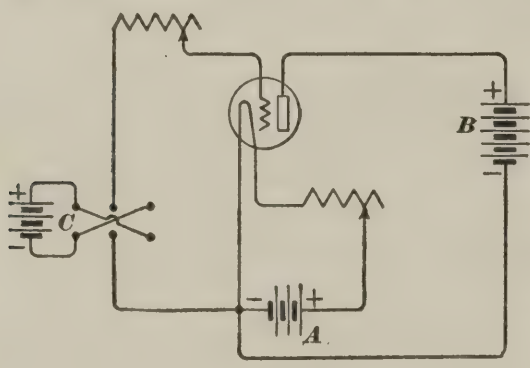


FIG. 4

If the voltage applied to the grid element is negative with respect to the filament, it will assist the effect of the space charge, and the plate current will be decreased by a corresponding amount. The voltage applied to the grid element may be adjusted to such a value that no electrons will flow from the filament to the plate. In this manner it is possible to produce large changes in the plate current by variations in

and reversals of the voltage of the grid battery. By this means small impulses or changes of voltage are utilized to affect large variations in the plate current. This feature is of great importance in the art of radio communication.

COMMERCIAL TYPE

24. A type of three-element electron tube is shown in Fig. 5. The **V**-shaped filament *a*, made of a twisted strip of platinum iridium covered with barium and strontium oxides, is mounted in the central portion of the tube. On each side of the filament is placed one of the two sections of the grid *b*. Outside of the grid *b* are mounted the two sections of the plate *c*. The grid is of cage-like structure and made of punched steel sheets. The plate sections are made of corrugated steel sheets, supported at the bottom by the glass base *d*, and clamped at the top about a small block *e* of insulating material. The top of the grid is supported by this block and the bottom by a lead-in wire through the glass base. The filament is held taut by a small spring-wire hook which is fastened to the insulating block. The glass base *d* supports and keeps the three elements in their proper relative positions. Better utilization of the liberated electrons is obtained by constructing the grid and the plate in two sections and mounting them so that the heated filament is nearly enclosed than when the plate and the grid are in single sections. The metal base *f* with its locking pin *g* fits into a socket made for this purpose, and locks securely in position. By means of spring contacts in the socket, connection is made with the three elements in the tube through the four external contact pins *h*. Two of these projections are connected to the filament inside of the tube, another one is connected to the grid, and the fourth one connects to the plate. A vacuum is maintained around the three elements within the glass tube *i*.

Other tubes, made by different manufacturers, vary considerably as to design features. In one type, which was largely used in the early days of the electron tube, the terminal

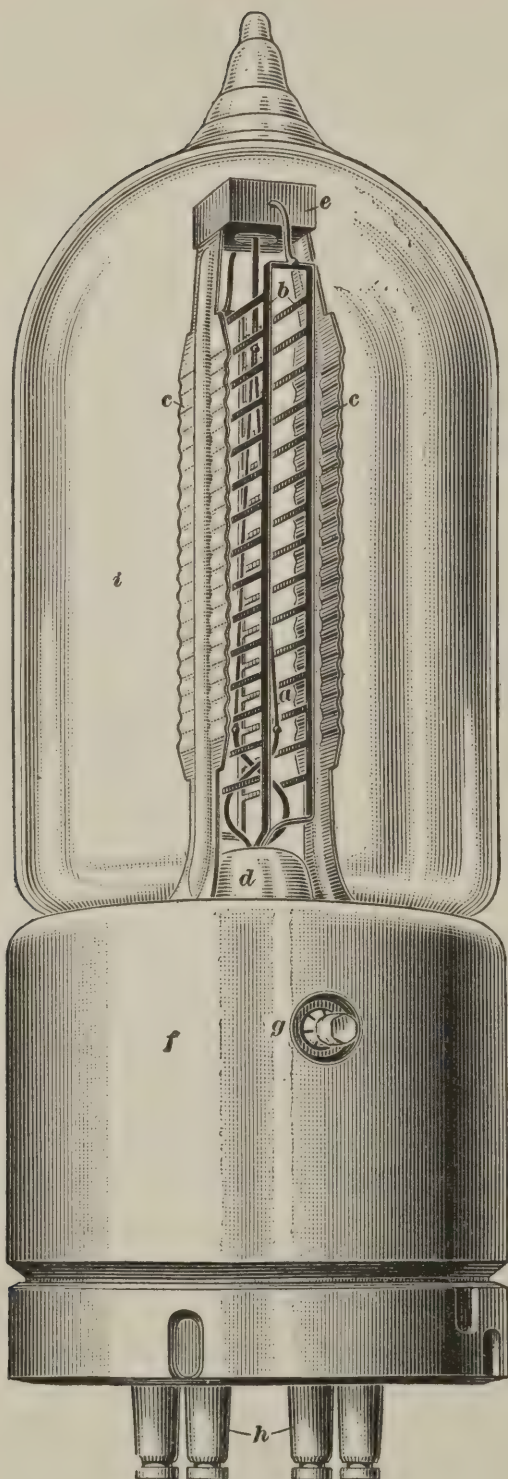


Fig. 5

connections to the elements were brought out to short flexible leads, no rigid supporting base being used. In a more recent type, the filament was a short straight wire supported at each end between relatively heavy wires connecting to the outside of the tube. The grid was a self-supporting helix of wire surrounding the filament and at a short distance from it, and this assembly was in turn surrounded by the cylindrical plate.

A tungsten filament is used in some electron tubes. This filament is operated at high temperature in order that a sufficient quantity of electrons be emitted from the filament.

Nickel is very extensively used for the grid and plate elements, especially in the smaller sizes where much energy must be dissipated per unit of area. This energy is that expended in sending electrons from the filament to the plate and is manifest as heat largely at the plate. The heating of the plate is one of the limitations of the capacity of the tube and

must be considered when designing the tube. Tungsten, as it can be safely heated to a higher temperature, will dissipate more energy per unit of area than will nickel, and has been used to a limited extent for the plate element.

CHARACTERISTIC CURVES

25. A graphical representation of the occurrences in a three-element electron tube is given in Fig. 6. The variation of plate current with changes and reversals of the voltage on the grid is represented by the curve *a*. The plate current will be zero with a certain value of negative voltage applied to the grid, as indicated at the extreme left of the figure. Numerical values differ largely with different sizes and kinds of electron tubes, and, therefore, definite values are not assigned to the grid-voltage and plate-current scales in Fig. 6. Raising the positive grid voltage causes the plate current to be increased until the curve becomes horizontal, or flat, at the extreme right of the figure, thus indicating that all the available electrons are flowing directly from the filament to the plate. The shape of the general characteristic curve is practically the same for any particular values of filament temperature and plate voltage, and since this is true other cases will not be considered separately.

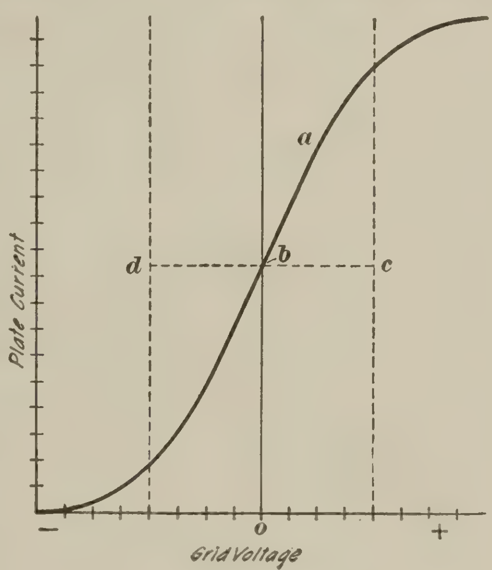


FIG. 6

26. The position of the vertical voltage line is not necessarily at position *b* as shown, but might be to the right as at *c* so as to cut the curve at a higher value, or at *d* so as to cut the curve at some lower value. In fact, electron tubes which are apparently identical in all other respects may vary considerably as to the practical value of the plate current with

zero value of grid voltage. The point is, however, an important one, rendering certain types of tubes especially applicable to particular uses.

USE AS A DETECTOR

EFFECT OF GRID

27. It is possible to use the three-element electron tube as a detector by disregarding the grid element, and using only the filament and plate connected as a two-element tube. The vastly superior operating characteristics of the three-element tube, however, have nearly eliminated the use of a tube employing only two elements as a radio detector. The characteristic curve of a three-element tube functioning as a detector is given in Fig. 7, in which the natural zero grid-voltage line cuts the plate-current curve at *a*. Assume that an alternating voltage of an intercepted radio signal is impressed on the grid and that *a b* and *a c* represent equal values of the voltage on each side of zero voltage. When the positive grid voltage is of value *a b*, the plate current will be represented by the length of the line *d e*, which is determined by the point at which the vertical voltage line through *b* cuts the curve. When the negative grid voltage reaches value *a c*, the plate current will be very small as indicated by the length of the vertical line between *f* and *g*. A positive portion of the incoming grid-voltage wave represented by *a b*, will produce a current change *b d* which, in the case shown in the figure, is approximately three times as large as the current change *f c* caused

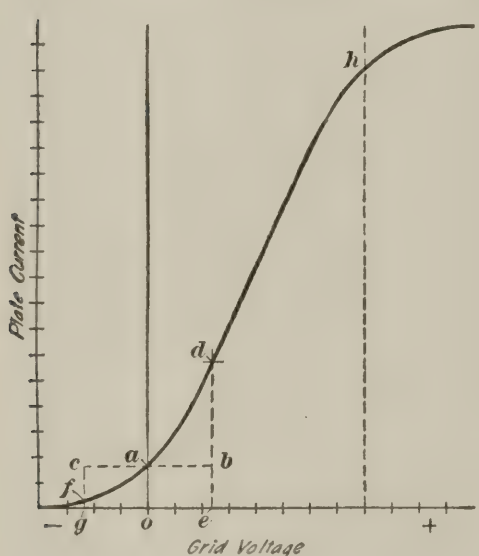


Fig. 7

by the negative portion of the incoming grid-voltage wave represented by *a c*. Larger variations in the grid voltage will control proportionately greater changes in the plate current, operation then being effective over a larger range on the characteristic curve. The foregoing gives rise to the principle of the detector action of electron tubes; namely, that like changes in the values of the voltage impressed on the grid can be made to produce unlike changes in the plate current.

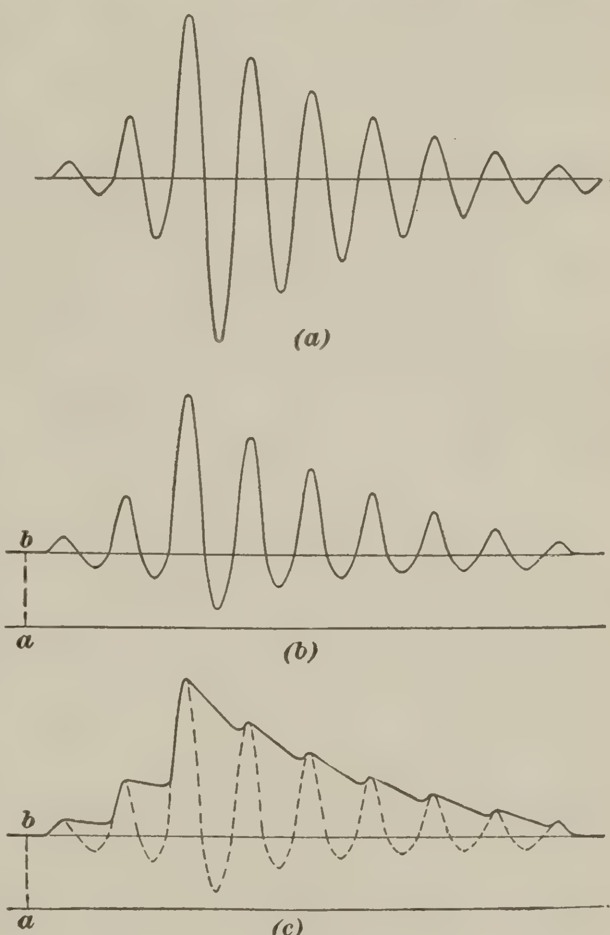


Fig. 8

VOLTAGE AND CURRENT CURVES

28. Curves showing the shape of the current or voltage waves active in the various circuits are given in Fig. 8. View (*a*) represents the shape of either the voltage or the current waves of the incoming damped radio-frequency signals just as intercepted by the antenna; the horizontal line represents the axis of the curve. View (*b*) shows the plate-current curve as affected by the action of the alternating or pulsating voltage applied to the grid circuit. View (*b*) further shows that the positive impulses of the grid voltage cause greater changes in the plate current than do the negative impulses.

29. When the tube is connected in a circuit such as the one shown in Fig. 9, the actual plate-current curve is more

apt to be similar to that represented by the curve of view (*c*), Fig. 8, than the one indicated by the curve in view (*b*). The condenser *a* of Fig. 9, shunting the telephone receivers *b*, or at least the capacity effect of the receiver cords in case no separate condenser is used, helps materially in smoothing out the

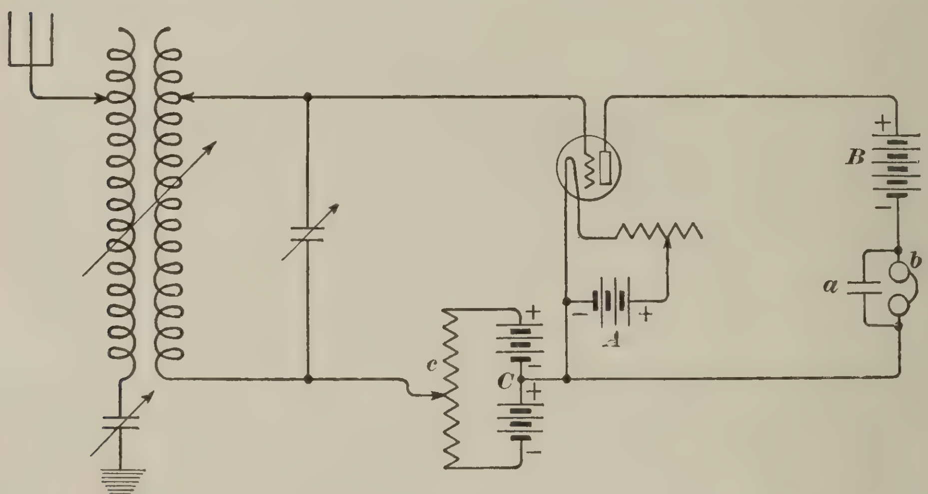


FIG. 9

radio-frequency impulses into the audio-frequency pulsations of the curve, view (*c*), in Fig. 8. It should be noted that the positive impulses have more than neutralized the smaller negative impulses, and that they have simultaneously been smoothed out, so that a click is given by the telephone receivers for each wave-train.

USE OF GRID BATTERY

30. The circuits of Fig. 9 differ from the circuits of some other detectors by the additional battery *C* and the resistance *c*. By changing the position of the movable contact point along the resistance *c*, the effective voltage of the *C* battery applied to the grid may be varied over its complete range of positive and negative values. The *C* battery is used to move the vertical voltage line to such a location that it will cut the characteristic curve of Fig. 7 near its top or bottom bend. If the properties of the tube are such that the natural zero grid-voltage line comes near the middle of the characteristic curve,

as does line *b* in Fig. 6, the movable contact point on resistance *c*, Fig. 9, would be changed toward the negative voltage end to move the vertical voltage line to a new position as at *a* in Fig. 7. The new vertical voltage line *a* is properly a zero-voltage line to incoming oscillations, although it may be considerably removed from the natural zero-voltage position for that tube by the action of the *C* battery. A positive grid voltage might be applied by the *C* battery instead of a negative one, in which case the vertical voltage line would cut the characteristic curve at some higher value as indicated at *h*. In this case, however, the negative part of the alternating current wave will be passed more readily than will the positive portion, but this difference will not be noticeable in the received signals. However, it is not desirable to operate near the top part of the curve, else the positive grid will take some of the electrons that belong to the plate. It might also happen, in fact occasionally does, that the natural-zero grid-voltage line comes on a bend of the characteristc curve, thereby removing the necessity for a *C* battery. The sole purpose of the *C* battery is, therefore, to control the location of the vertical-voltage line, which, after the *C* battery voltage is once adjusted properly, becomes the zero grid-voltage line, so far as the operating characteristics of the detector tube are concerned.

31. If the vertical voltage line intersects the characteristic curve near the center, the alternating grid voltage will produce equal plate-current changes with equal positive and negative impulses. One set of pulsations will then largely neutralize the other, and no detector action will be accomplished by the tube. The values *a b* shown on views (*b*) and (*c*) of Fig. 8 represent the value of the normal current in the plate circuit, and the changes caused by the variations of grid voltage are impressed on it, giving the curves of varied shapes as shown. Only one wave-train is given in this illustration, but this operation is repeated for every wave-train, succeeding ones being connected by the constant values *a b* of plate current passing during the brief intervals of quiet. The dotted waves in view (*c*) are the same as the solid-line curve of view (*b*);

they are used merely to show the derivation of the plate-current curve that is drawn as a heavy line, view (*c*).

In some receiving sets the *B* battery and telephone receivers are interchanged from their relative positions as given in the plate circuit of Fig. 9. The negative terminal of *B* battery would then connect to the filament, and the telephone receivers would be directly connected to the plate of the tube. This latter arrangement seems particularly useful where a storage battery is used for the *B* battery. With the negative terminal of the *B* battery connected next to the filament, this point could be connected to ground with no serious results. The arrangement as indicated is perhaps as much used as any; but if one does not work, other arrangements should be tried until best results are obtained. This interchangeability of the *B* battery and the telephone receivers holds, in general, for most of the plate-circuit connections which will follow.

USE OF GRID CONDENSER

32. Another method of using a three-element electron tube as a detector is shown in Fig. 10. This circuit differs from Fig. 9, in that the *C* battery is omitted and a condenser *a*

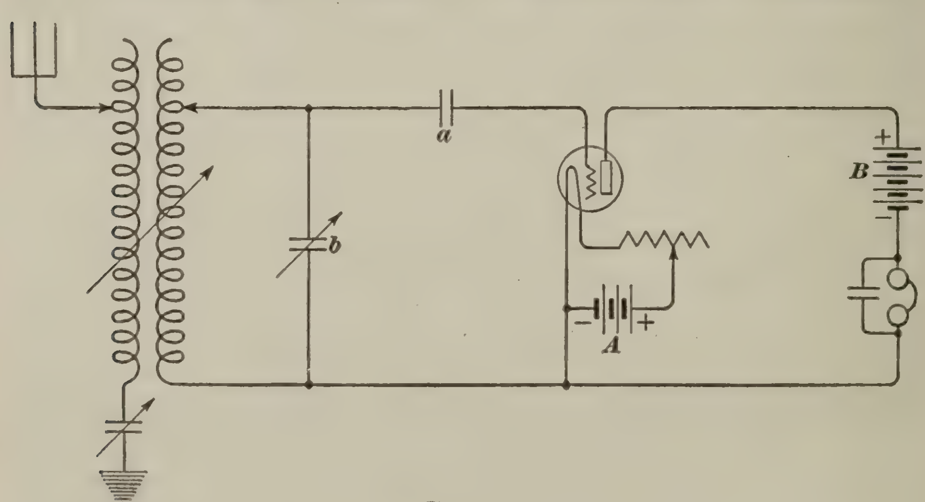


FIG. 10

of small capacity is connected in the grid circuit of the tube. A condenser connected in such a location is very commonly called a *grid condenser*. This condenser does not per-

mit a direct current to pass through it, hence no constant voltage can be impressed on the grid as in the former condition. For any given value of filament temperature and plate voltage a constant current will pass through the plate circuit, its value depending primarily upon the characteristics of the tube. When a wave-train of radio frequency is impressed upon the oscillating circuit, the condenser *b* in that circuit becomes alternately positive and negative, due to the oscillatory current set up in that circuit. This changing voltage charges the grid positively and negatively through the grid condenser *a*. Each time the grid becomes positive, some of the electrons will flow from the filament to the grid, but during the negative half-cycle no electrons will be attracted to the grid. Neither will the electrons that have been accumulated be liberated from the grid during the period of negative charge. The successive positive charges impressed on the grid by the condenser *a* will produce a cumulative effect which results in the grid becoming negatively charged from the electrons it has attracted. This accumulated negative charge on the grid opposes the flow of electrons from the filament to the plate by adding its effect to the opposing space-charge effect, and the plate current is, therefore, decreased during the remainder of the wave-train.

USE OF GRID LEAK

33. In order that the grid may be in its original condition, that is, with no charge, upon the arrival of the following wave-train, it is necessary to remove the negative charge from the grid. If the grid condenser has a poor dielectric, this charge may leak off to the filament through the dielectric and the secondary winding of the oscillation transformer. In some cases the charge very probably leaks off through the grid supports, or if there is some gas in the tube, this gas may form the conducting medium. When the tube has a very high vacuum, an artificial means for insuring a leakage path for the grid charge may be provided by shunting the grid condenser *a*, Fig. 11, by a high resistance, such as is represented at *b*. A resistance used in this manner is commonly called a *grid leak*,

and may be anywhere from 500,000 to 2,000,000 ohms. Although the high resistance is often of fixed value, it is sometimes very desirable to use one that is variable, as fine tuning of the set may often be assisted by making changes in the value of this resistance.

34. Practically the same results may be attained by connecting the grid leak between the grid terminal *c* and the negative filament terminal *d*, as then the charge can leak off directly to the filament and be dissipated. As only one main charge is accumulated for each wave-train, the radio-frequency oscillations will be converted into audio-frequency impulses, and

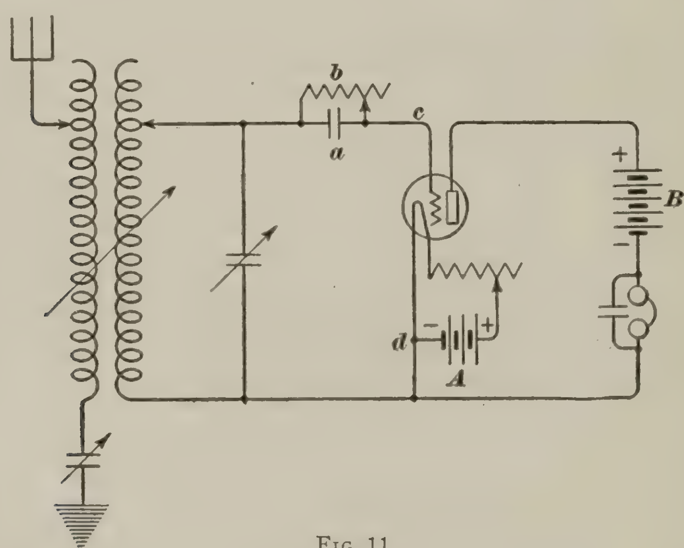


Fig. 11

thus produce audible signals in the telephone receivers. It should be noted that when a grid condenser is used, no *C* battery is required. This feature, together with the fact that the operation will be satisfactory at practically any point on the characteristic curve of the tube, is a point decidedly in favor of this circuit arrangement.

A curve of the plate current would be very much like view (*c*) of Fig. 8, except that the heavy-line curve would be inverted, that is, the humps due to the incoming signals would decrease the normal plate current *a b*. This is due to the fact that the plate current was decreased because the incoming charges decreased the flow of electrons. No material differ-

ence is discernible, however, between the sounds in the telephone receiver, whether the current impulses increase or decrease the magnetic pull on the diaphragm.

USE AS AN AMPLIFIER

35. Definition.—It has been found that certain variations of voltage applied to the grid circuit of a three-element electron tube produce corresponding variations in the current of the plate circuit. When these circuits are properly adjusted, the electron tube acts not only as a detector, but also as an **amplifier,** inasmuch as it amplifies, or strengthens, the received signals. This feature is of importance in radio communication, where the incoming signals are very weak, and by applying the amplifying properties of an electron tube or several of them, these signals can be made more intense, and hence better for reception.

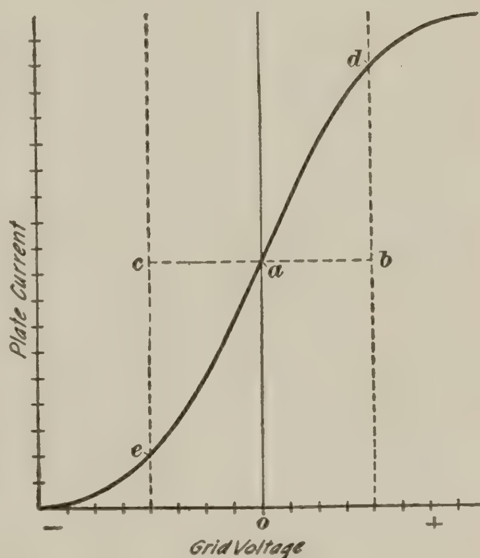


FIG. 12

36. Explanation of Action.—The amplifying action of an electron tube is best explained by considering the characteristic curve of the tube and the effects produced thereon by changes in the incoming signals. Consider a case where the zero-voltage line cuts the characteristic curve at its mid-point, as *a* in Fig. 12. If equal alternately positive and negative voltages are applied to the grid as shown by values *a b* and *a c*, respectively, the vertical voltage line will move in corresponding right and left directions and, for the positions of maximum movements, will cut the characteristic curve at points *d* and *e*, respectively. The equal distances *a b* and *a c* represent the equal alternating voltages applied to the grid

of the electron tube. Values to the right of the zero line are positive, and those to the left are negative. The change *a b* of the positive grid voltage produces a change *b d* in the plate current, whose normal value is represented by *o a*. Similarly, a change *a c* in the negative grid voltage causes a change *c e* in the plate current from its normal value. Equal variations of grid voltage *a b* and *a c*, produce equal changes in the plate current as is shown by *b d* and *c e*. When an alternating or pulsating voltage is impressed on the grid circuit, pulsations occur in the current of the plate circuit, but the important point is that slight changes in the voltage applied to the grid produce large changes in the flow of electrons and, therefore, of the plate current.

37. The changes of current in the plate circuit occur simultaneously with the voltage changes in the grid circuit, hence there is no accumulation of charges on the grid, and a grid leak need not be used. The current in the plate circuit of a three-element electron tube used as a detector is much larger than the rectified pulsating current in the grid circuit, and the tube thus performs an amplifying action, as well as a rectifying action. For this reason the electron tube is superior to other types of detectors, and is in quite common use. If the zero grid-voltage line does not come near the center of the curve of Fig. 12, a *C* battery of proper voltage may be used, as was done in the case of a tube when used as a detector. If the zero value were near either the upper or the lower bend of the curve, detector action would result, with one-half of the received wave amplified more than the other.

It should be understood that the filament, or *A*, battery actually supplies the electron charges present in the tube, that the plate, or *B*, battery attracts them, and that the grid, or *C*, battery, if one is used, controls them to a large extent. The incoming signals are very weak, and by their action produce charges on the grid which control the flow of electrons. The effect of the grid may be compared to the movement of the gasoline throttle lever by the driver of an automobile, the pulling of the trigger of a gun, or the movement of the con-

troller handle by the motorman on a street car. The application of a relatively small amount of energy controls great changes of available energy.

RECEIVING CIRCUITS USING ELECTRON TUBES

DETECTOR AND AMPLIFIER

38. Fig. 13 shows circuit connections for two electron tubes, each of the three-element type. Tube *a* acts as a detector and amplifier and tube *b* as an amplifier. The incoming oscillations are rectified and also amplified to some extent

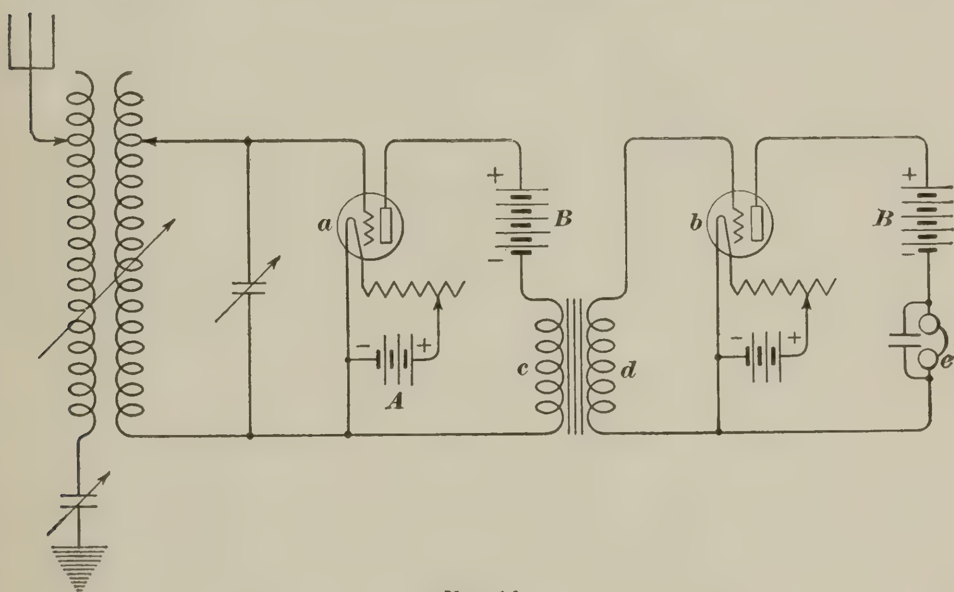


Fig. 13

in tube *a*. The detector action changes the radio-frequency oscillations to audio-frequency current impulses. These current impulses enter the primary coil *c* of an iron-core transformer. They are transformed into an alternating current and the alternating current passes from the secondary coil *d* to the grid circuit of the tube *b*. The greater part of the amplification occurs in tube *b*. The amplified and rectified current from tube *b* passes through the telephone receivers *e* and produces strong and intelligible signals.

Connecting the lower ends of the windings *c* and *d*, and grounding the junction has, in some cases, been found effective in reducing the noises produced by the tubes. Except for the connection suggested in the preceding sentence, the *B* battery of the tube *a* might just as well be connected between coil *c* and the filament as between that coil and the plate. Similarly, the plate battery of tube *b* might be interchanged with the telephone receivers. It is important, however, that the positive terminal of the plate battery be always connected toward the plate.

The ratio of numbers of turns of wire in coils *c* and *d* varies considerably, but is usually somewhat less than one to ten. Good operation has been secured by using air-core coils of many turns instead of iron-cored coils. It is important that these coils have a very great number of turns for best operation, and, to reduce the bulk, they are commonly made of fine wire. Very close coupling between the coils is desirable, especially where air-core coils are used. As only a minute current is carried, the power lost in these transformers is usually negligible. It is very probable that some of the radio-frequency currents get over into the grid of the tube *b* and are there further rectified. This, however, is not considered an objection.

TWO TUBES WITH COMMON BATTERIES

39. A somewhat different wiring arrangement is shown in Fig. 14, in which only one *A* battery and one *B* battery are used. One common resistance *a* serves to vary the voltage applied to the filaments, and both filaments receive the same voltage. Using two rheostats, one for each filament, has certain advantages, as the voltage, and consequently the filament current, of each electron tube, may be independently controlled. This is particularly desirable in case the characteristics of the two tubes are somewhat different, as is often the case in commercial tubes. Another change in the circuit is the addition of the grid condenser *b* to the grid circuit of the detector tube. The grid leak *c* is often added, when the grid condenser is used, for the purpose, as has been explained,

of allowing the charge on the grid to leak off to the filament, so as to maintain stable operating conditions.

40. As the plate current is directly dependent upon the flow of electrons in the tube, any change in this flow will affect the plate current. As has been explained, the detection and amplification of the radio signals depend wholly upon this principle. The strength of the signals may be controlled over a considerable range by changing the filament temperature through changes in the filament current. Thus if the signals from a near-by station come in very strong, the electron flow may be decreased, and the signals will still be strong enough

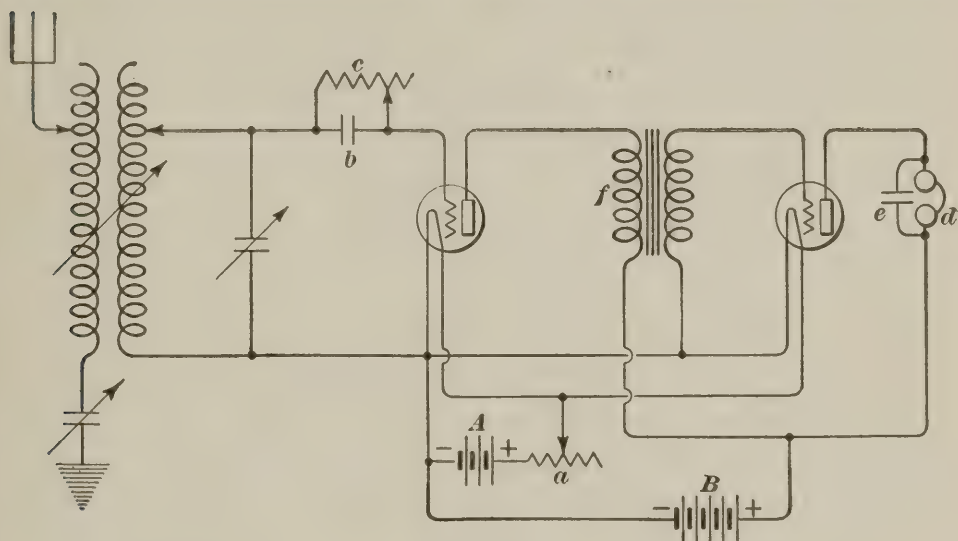


Fig. 14

for the operator to receive them satisfactorily. Burning the filament at the lower temperature possesses the advantage that decomposition is not so rapid, and its life is much longer. Similarly, burning the filament at a higher temperature, or so that it glows brighter, will increase the electron flow, and the incoming signals will be amplified to a greater degree. This holds true over narrow limits, and should not be carried to such an extent as to burn out the filament. Some change in the degree of amplification of the signals may be accomplished by varying the voltage of the *B* battery, but, while this is important with some types of tubes, it is not commonly used as better control is furnished by the *A* battery.

In some cases a *C* battery may be used, and when this is done it is connected between the filament and the grid in a manner similar to that illustrated and described for the detector alone. A *C* battery is seldom used on amplifier tubes, as only those whose characteristic curves fulfil the required conditions are selected for this use. When trying to pick up a station, the filament is usually burned at some high value of current, and when sharper tuning is being made the filament current may be decreased. This procedure very frequently leads to an appreciable elimination of some of the interference from other stations.

The direct current from the *B* battery in passing through coil *f*, Fig. 14, of the transformer does not induce any current in the secondary coils. This is according to the principle of transformer action, that only a varying current in one winding induces a current in the other winding. It is therefore impossible for the steady current to be transferred from one circuit to another, although the alternating-current signals pass through with very little opposition.

CASCADE CONNECTION

41. Cascade Amplification is the name applied to the method of using two or more electron tubes in such a way as to amplify successively radio signals. If the received signals are very weak, it is very often desirable, and perhaps even necessary, that they be sent through several tubes, one after the other, to make the signals of sufficient strength to be read easily. Each tube thus receives the incoming signals and, after amplifying them to a certain extent, passes the wave energy on to the next tube for further amplification. From the last electron tube in the series the signals go through the telephone receivers with sufficient strength to be received intelligbly.

RESISTANCE COUPLING

42. A type of connection for two electron tubes using a form of resistance coupling is illustrated in Fig. 15. A resistance *a* of several thousand ohms replaces the transformer of

Figs. 13 and 14. This resistance is connected in the plate circuit of the first tube *b*, Fig. 15, and in the grid circuit of the second tube *c*. Any changes of current strength in the plate circuit of the first tube will be communicated to the grid of the second tube, where the current impulses will be further amplified.

A condenser *d* prevents the establishment of a direct current in the grid circuit of the amplifier tube *c* and consequent interference with the flow of electrons therein. The introduction of the condenser *d* in the grid circuit necessitates the use of a grid leak resistance *e* of rather high value to prevent the

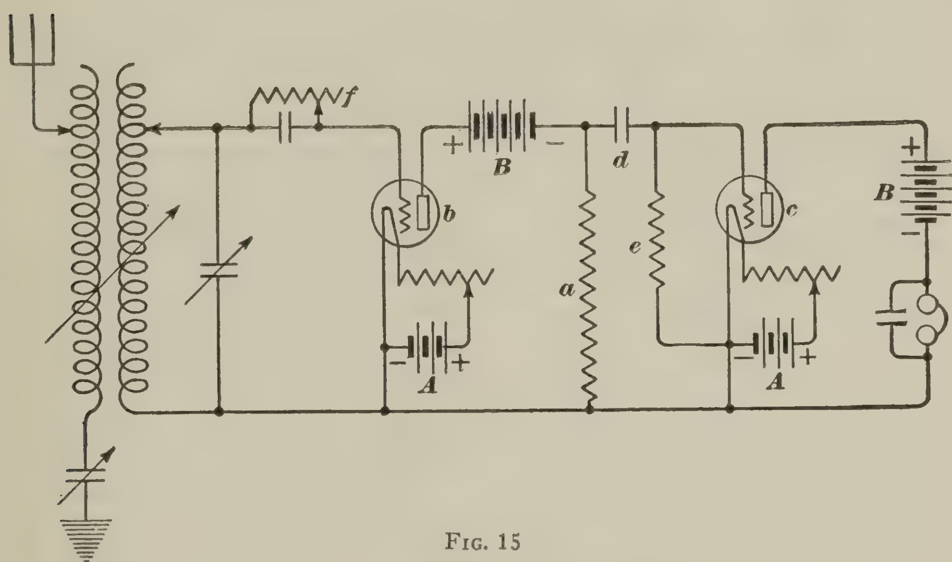


FIG. 15

accumulation of an excessive negative charge on the grid. The grid leak *e* is connected directly across the grid and filament terminals in this case instead of directly across the condenser, as is the case with the grid leak *f*. No material difference in the operation of the two methods of connection is usually evident, and although they may be considered interchangeable, the method in which the resistance shunts the condenser is the more commonly used. The coupling resistance *a* is usually of the order of several thousand ohms. The *B* battery required with this type of coupling is practically the same as that required with any other type of coupling. As this type of coupling is entirely independent of the frequency of

the current, it amplifies signals of all frequencies equally well, and without distortion. It is also very frequently used in radio-frequency amplification work with equal satisfaction. The *B* battery near tube *b* in resistance coupling is frequently removed from the location shown in Fig. 15, and connected between the resistance *a* and the horizontal line below it. By some it is claimed that better amplification and quieter operation may be obtained by this change, but it is probable that local operating conditions affect the operation to an equally large extent.

INDUCTIVE COUPLING

43. Another method of coupling the various electron tubes together is represented in Fig. 16. As may be seen by inspection of this figure, the coupling from tube to tube is accomplished by inductance, coils *a* and *b* giving what is known as an *inductive coupling.* Their action is nearly the same as when ordinary transformer windings are used, except that in this case only single coils are used, giving practically the effect of autotransformers.

Perhaps the easiest way to understand the workings of this circuit arrangement and the component devices is by a description of events in the order in which they occur. Intercepted radio waves set up oscillations in the antenna which are transferred to the closed oscillating circuit. From here they are impressed on the grid of the first electron tube *c,* where they produce much larger changes in the current in the plate circuit of that tube. The radio-frequency pulsations from the plate of tube *c* combine with the current from the *B* battery. This pulsating current is then applied to the grid of tube *d*. It has been found that the signals in any circuit are at a maximum when that circuit possesses a natural wave-length the same as that of the wave it is receiving. For this reason a variable condenser *e* is often connected in parallel with the coil *a,* and the plate circuit may then be tuned to the incoming current wave. Coil *a* should not have an iron core, because then its opposition to the radio-frequency currents will be so great that very little current will be permitted to pass through it.

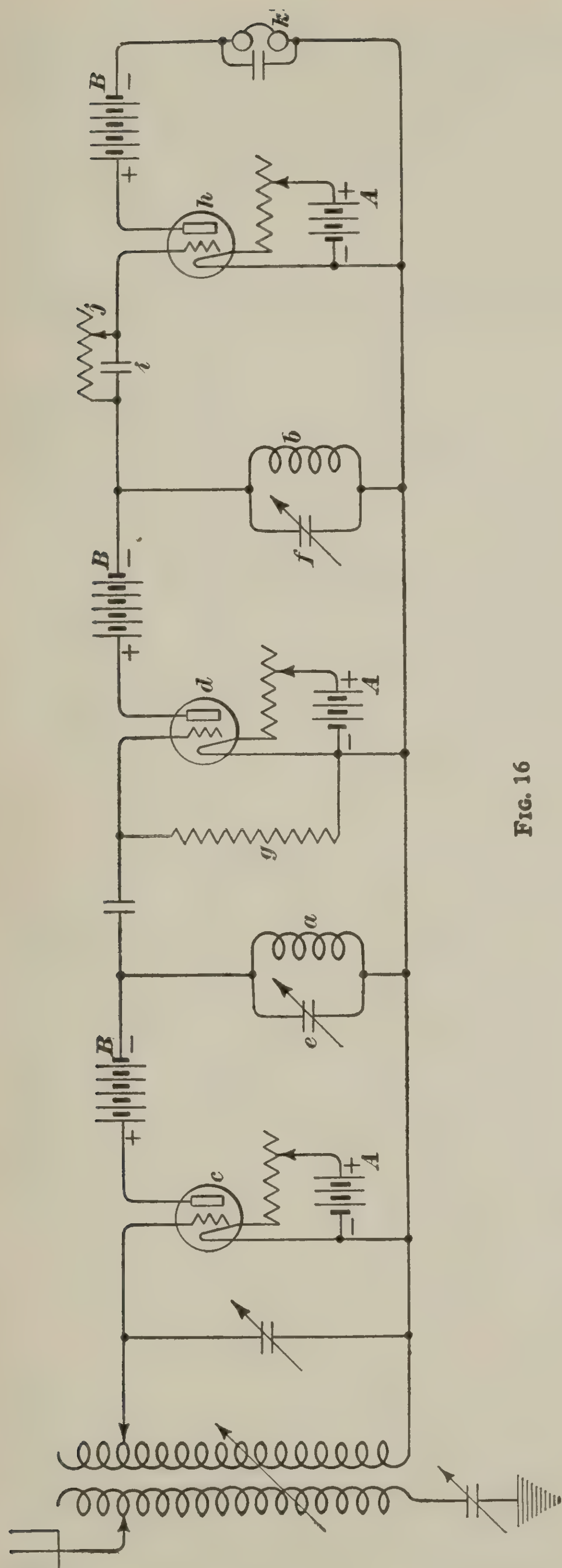


Fig. 16

The action of tube *d* and its tuned plate circuit with coil *b* and condenser *f* is identical with that which has just been described, and the signals are amplified to a still greater extent. A grid leak *g* may be connected as shown to provide a path for the negative charges to leak off, should this be necessary. With tubes as used for amplifiers only, this is seldom necessary, and in many cases no provision is made for such connection.

44. The electron tube *h* performs the detector action and amplifies the signals to some extent. In some cases, the amplification of the radio-frequency signals just as received is advocated on the theory that the action of the detector tube is best when the current to be rectified in it is a maximum. With very weak signals, such as are intercepted by the

antenna, the detector action might be rather poor. By amplifying the received signals before they are sent through the detector tube, maximum response in telephone receivers should be obtained. The detector tube *h* is provided with a grid condenser *i* and grid leak *j*, connected in the usual manner. By means of the charge that accumulates on the grid condenser, single impulses of direct current are established in the plate circuit which produce audible sounds in the telephone receivers *k*.

45. The primary function of the inductance coils in the plate circuits of the two amplifying tubes *c* and *d* is to assist in securing maximum amplification of the signals. The possibility of tuning these circuits is also of importance, as by tuning them accurately to the incoming waves, interference from radio signals on other wave-lengths may be largely, if not totally, eliminated. In this circuit also it is possible to connect the *B* batteries below the tuned circuits. There is no doubt that this latter connection has given better results in some cases, but it is doubtful that it would in all cases.

RADIO- AND AUDIO-FREQUENCY AMPLIFICATION

46. A very desirable arrangement where large amplification of the signals is necessary is to arrange several tubes so that some of them amplify the original waves at radio frequency and others amplify the audio-frequency rectified signals. The current will be amplified just as received by the aerial, then rectified by a detector tube, and further amplified at audio frequency by other tubes. Such an arrangement is represented in Fig. 17, in which two tubes *a* and *b* amplify the radio-frequency signals, which then pass through a detector tube *c* and are further amplified at audio frequency by tubes *d* and *e*.

47. The circuit connections, Fig. 17, follow the usual arrangement for the various devices. All the tubes are supplied by common *A* and *B* batteries, a rheostat *f* serving to alter the current supplied to the filaments. In order that the proper *B*-battery voltage, for most favorable operation, may

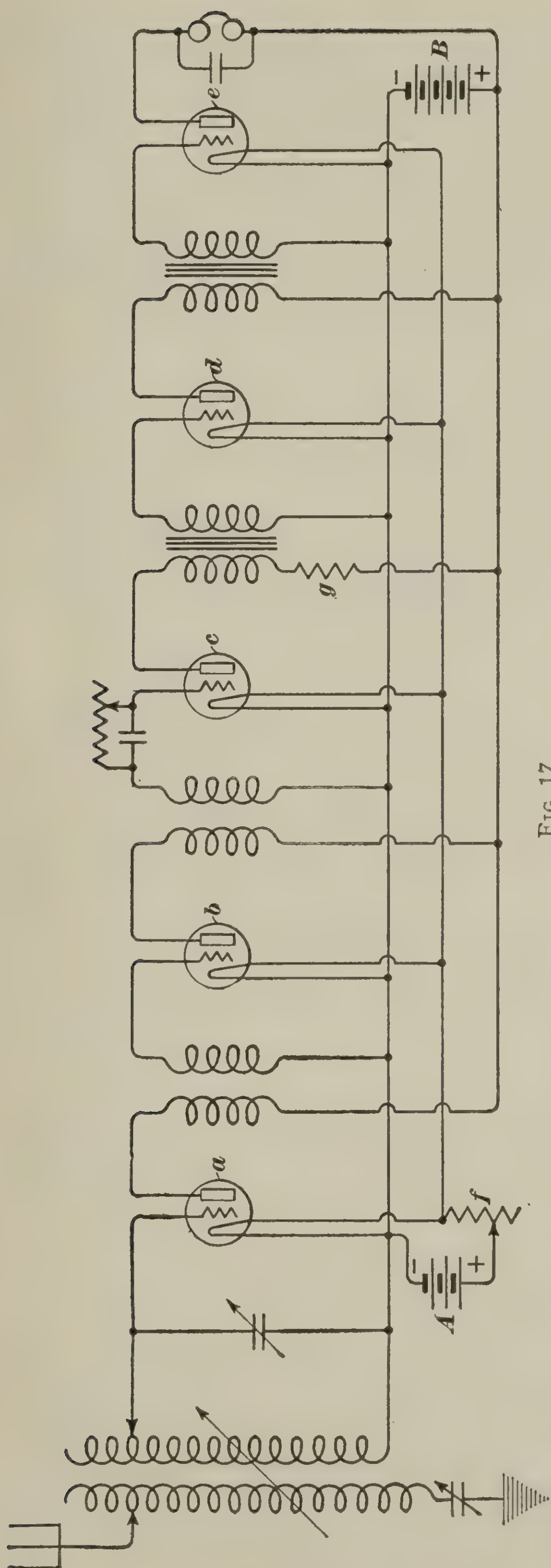


Fig. 17

be impressed on the plate of the detector tube c, a resistance g is provided. Such an arrangement will prove very satisfactory in use. Due to reaction between the various circuits, and phenomena set up when in operation, a larger number of tubes is seldom used to amplify signals. With proper care, however, seven or even more electron tubes may be satisfactorily used to detect and amplify radio signals. Where several tubes are used with this cascade arrangement, it has been found that operation is often quieter if each tube is operated by a separate battery. This applies more particularly to the B batteries as the operation of the individual tubes depends more directly upon the value of the B-battery voltage.

REGENERATIVE AMPLIFICATION

48. Instead of using a cascade amplifier, another method is in

use, and is known as *regenerative amplification.* Only one electron tube is used, and instead of sending the amplified and rectified signals through another tube, these impulses are passed through the same tube again. A *feed-back transformer* transfers some of the energy from the plate circuit back into the grid circuit, and the impulses then undergo further amplification. In this manner the same tube may be simultaneously acting as a detector and amplifier, and performing both functions satisfactorily.

49. A regenerative amplifier is represented in Fig. 18, in which *a* is the usual electron tube. The inductance *b* may be

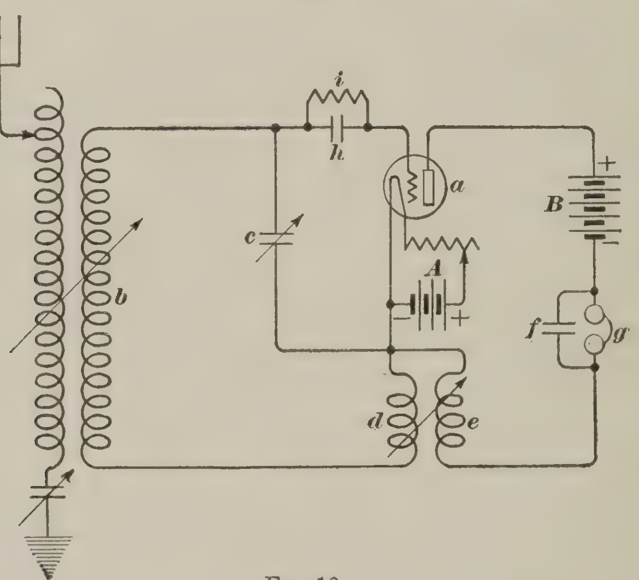


FIG. 18

inductively coupled to the antenna circuit, or it may form the secondary of an amplifying transformer in the plate circuit of another electron tube. The variable condenser *c* is the usual provision for tuning the oscillating circuit to the same wavelength as the antenna circuit, and largely determines the efficiency of operation of the set. A small inductance *d* in the oscillating circuit forms the secondary of an air-core transformer of which *e* is the primary. The coupling between these coils should be variable so that they can be placed in such relative positions that only the desired amount of energy will be supplied back to the grid circuit. The connections of the coils

should also be such that the energy transfer is in such a direction or relation that it helps rather than hinders the current already in the grid circuit. The condenser *f* provides a good path for the high-frequency currents in the plate circuit, around the telephone receivers. The high-frequency oscillations in the plate circuit excite the primary coil *e* of the air-core transformer, the direct current from the *B* battery not affecting the transformer except to cause a small constant current to pass in the primary winding. The electromotive force induced in the secondary of the transformer is impressed on the grid of the electron tube and controls larger changes in the plate circuit. The telephone receivers *g* are then operated and produce audible signals. The condenser *h* and resistance *i* perform their usual functions as component parts of the detector circuit.

50. Many other circuit arrangements for regenerative amplification have been produced, and some have given remarkably good results. In general, however, their operation does not appear stable, that is, consistent for a fair length of time, and unusually accurate adjustment is required. Therefore, they have not come into general use, although the feed-back principle is often employed in other electron-tube circuits. This instability is probably due largely to the electron tube, and with refinement of design and construction of the component devices, this type of set should give very good operating characteristics. The economy of using one tube as both detector and amplifier is a desirable feature, and has much to commend it.

USE AS AN OSCILLATOR

51. A generator for high-frequency undamped or continuous alternating-current waves is desirable in low-power sending sets as well as in the long-range equipment. The electron tube, when connected in circuits of special types, has proved to be a very reliable *oscillator,* and with proper arrangements will establish an alternating current over a large range of wave-lengths and frequencies. Although practical uses do

not call for such an excessive range of frequencies, the electron tube has been made to establish currents varying from one cycle per second up to several million in a like interval of time. The significant feature is that the same tube may be used to produce currents over this wide range of frequencies, the change beng made and controlled largely by means of variable electrical properties of the oscillating circuit. The type of tube which is used as a detector or amplifier may be used also as a generator, but this is neither the common nor the preferred practice.

52. Electron tubes have been used in many different circuits to establish alternating currents. Most of the circuits transfer some of the power in the plate circuit back to the grid circuit, where it undergoes a further amplification. If a correct portion of every oscillation produced in the plate is fed back into the grid circuit, the alternating-current wave will be continuous. The electrical properties of the plate circuit determine to a large extent the frequency of the established current.

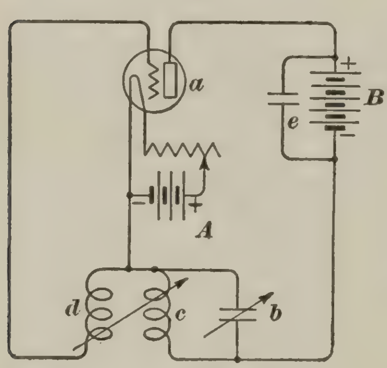


Fig. 19

53. Fig. 19 shows a simple circuit arrangement for producing an alternating current by the use of an electron tube *a*. The condenser *b* and inductance *c*, which form an oscillating circuit, are given such values that their natural period of vibration corresponds with the desired frequency. The inductance, or capacity, or both, may be made variable if it is desired to change the frequency of the current. An inductance coil *d* is coupled to coil *c*, and thus receives some energy from the oscillating circuit. The degree of coupling must be such that the feeble currents in the grid circuit will, when amplified, maintain the current variations and cause the plate oscillations to be continuous. When the electrical properties are once established, the tube will oscillate for a considerable time with very little variation. Due to the stable

frequency of oscillation, the electron tube is largely used as a producer of continuous waves to be used in accurate radio measurements. The condenser *e* is not always used, but when installed it provides a good path for the oscillating current in the plate circuit. This current then does not have to pass through a rather high resistance *B* battery. The established current may be used in another circuit by coupling a coil to coil *c*, or to any other coil placed in the oscillating circuit.

54. The inductance or coupling coils *c* and *d* must be connected so that the oscillations in the grid circuit assist those in the plate circuit. These coils need not be very large, as only a small amount of energy is transferred. In some cases it may be possible to wind both coils on a common supporting core, but in that case it would be impossible to vary the coupling.

The original electrical disturbance in the oscillating circuit might be due to an electron discharge in the tube, which might be caused by a change in the capacity of the circuit, or by a slight rush of current produced by closing the circuit of the *B* battery. Through the action of the coils *c* and *d* the grid voltage is affected. The amplitude of the first cycle on starting might be quite small, but the cumulative effect of the feedback action would cause successive waves to be larger until a balance was reached. At this point the energy generated would just maintain a current of a certain strength, and a pure unvarying wave of alternating current would be produced in the oscillating circuit or in the circuit coupled to the plate circuit. The actual operation of the tube is quite like its action as a regenerative amplifier, as it actually amplifies the small amount of energy transferred to the grid circuit from the plate circuit.

55. The oscillating circuit may be entirely separate, and be connected to the grid and plate circuits by inductance coils, as is represented in Fig. 20. The oscillating circuit formed by the inductance coil *a* and condenser *b* controls the oscillations of the current established in the plate circuit as in the preceding case. An inductance coil *c* is coupled to the oscillating circuit,

and by transformer action transfers the current to the inductance coil *a* and its connected circuit. By means of an inductance coil *d* an electromotive force is impressed on the grid of the electron tube which causes an oscillating current to be established in the plate circuit, but with a greater amplitude. The condenser *e* provides a good path for the oscillating current in the plate circuit to pass around the *B* battery.

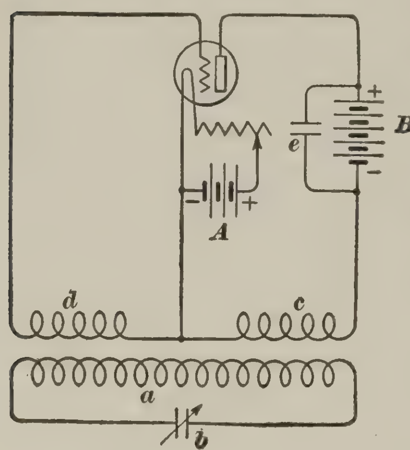


Fig. 20

Fig. 21 shows an oscillator coupled to an antenna circuit *a and b*, which in itself forms an oscillatory circuit. The action is similar to that described in connection with Fig. 20, as the antenna takes the place of the closed oscillatory circuit.

It is very difficult to give design data for oscillators. This is due to the fact that the oscillation of a tube depends upon several variable factors. The value of the *B*-battery voltage is important, and quite different for different tubes. The voltage of this battery is, in general, quite high, as a relatively large plate current is desired when oscillations are sent out. One of the simplest tests to determine when an audio-frequency tube is oscillating, is to couple a coil of a few turns of wire to some part of the oscillating circuit, and listen to the induced current with a set of telephone receivers. If the frequency is above audibility this method is not applicable. In the case of radio frequencies a short gap in the oscillating circuit will often show when the tube is oscillating. For this test, unfasten the lead to the condenser and slowly pull the

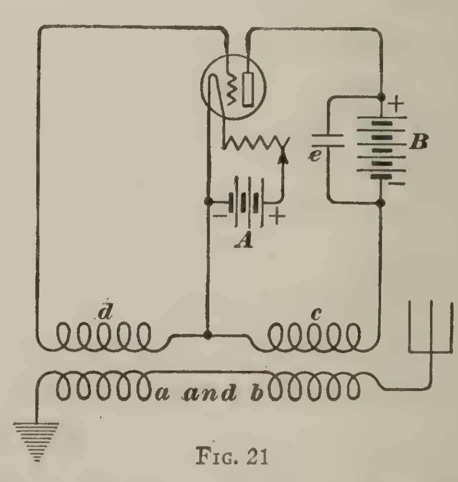


Fig. 21

connecting wire away from the condenser terminal. While there is still a minutely short gap, there should be a fine spark which will die out as the gap length is increased. This is only a rough test. The most sensitive and absolute test is by placing in the oscillating circuit a sensitive radio ammeter, which will deflect when an oscillating current is established.

ELECTRON TUBE AMPLIFIER AND CRYSTAL DETECTOR

56. It has been found that an electron tube is often more efficient when used for only one operation, that is, either as an amplifier or a detector. When a tube is adjusted for amplifying the incoming oscillations, it is usually more efficient in performing this operation than were it put to the task of both

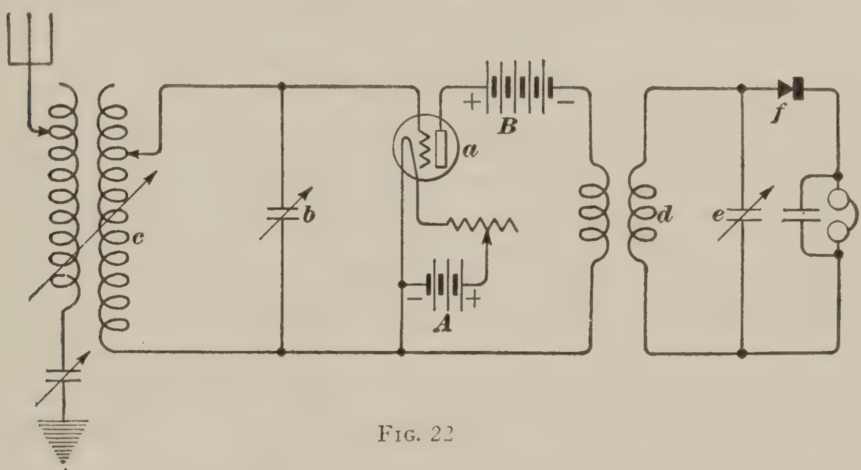


Fig. 22

amplifying and detecting. Two or more electron tubes connected in such a way that one of them rectifies the incoming oscillations and the other amplifies them, answer the purpose.

To obtain the full amplifying power of an electron tube, a circuit as shown in Fig. 22 is sometimes used. The electron tube *a* amplifies the incoming oscillations received from the oscillating circuit *b c* at their natural frequency. These amplified high-frequency oscillations are then transferred inductively to the oscillatory circuit *d e*, which is tuned to correspond with the circuit *b c* and with the plate circuit of the electron tube. These oscillations are then rectified in the usual way by the action of the crystal detector *f*, and in passing through the telephone receivers they produce a clear musical sound.

UNDAMPED-WAVE RADIO COMMUNICATION

SENDING TELEGRAPH SIGNALS

INTRODUCTION

DEFINITION OF TERMS

1. Instead of using damped radio-frequency wave-trains, another system of radio communication makes use of a series of high-frequency radio waves in which the amplitude of the waves remains practically constant throughout the series. By **undamped-wave radio communication** is meant the system in which the signal, if continued, would be an unbroken or undamped series of waves of alternating current. This is in contrast to damped-wave radio telegraphy in which the radiated energy is broken up into short wave-trains, each consisting of several cycles of high-frequency current. As the radio-frequency waves are continuous, during one element of a signal, the name *continuous-wave radio telegraphy* is often applied, and is frequently used interchangeably with that of undamped-wave radio communication. The waves in radio-telegraph practice may be interrupted at intervals into short and long groups to give the dots and dashes of the telegraph codes.

ADVANTAGES OF SYSTEM

2. The following are some of the advantages of the undamped-wave radio system: When damped-wave signals are used, all of the cycles of current are not of the same ampli-

tude, and despite every effort, tuning cannot be accurate enough to include all of the waves to the best advantage. In case continuous waves of constant amplitude are used, the tuning at the receiving station may be made very sharp, and on one definite wave-length. In the damped-wave system, the antenna is energized for only a part of the time, while in the undamped system the power supply is continuous, a fact which causes a larger rate of energy radiation in the latter case.

USE OF DAMPED WAVES

3. In the early days of radio communication the various spark systems of damped-wave signaling provided practically the only satisfactory method of producing radio-frequency current oscillations; hence this system was in almost universal use. With the development of the art, and by the application of new principles, several devices have been produced which enable radio communication to be established by using continuous alternating currents of exceptionally high frequency. The use of damped waves at the present time, particularly in small power sets, is due largely to the fact that such transmitting apparatus may be constructed and operated very conveniently and cheaply, especially in these sizes.

HIGH-FREQUENCY ALTERNATORS

ALEXANDERSON ALTERNATORS

4. The *Alexanderson alternator* is an alternator of very high frequency, and the generated energy may be radiated direct from the antenna as produced. This type of alternator has been described in a previous Section. Considerable expense is attached to the installation of this set, partly on account of the large amount of auxiliary apparatus required. Great success has accompanied the use of this equipment, and it promises to become one of the most important and common machines in long-distance radio communication.

5. Alternator in Antenna Circuit.—As the Alexanderson alternator generates voltage waves at radio frequency, it may be connected directly in the antenna circuit, as indicated at *a* in Fig. 1. In the above case tuning to an exact wave-length is accomplished by varying the number of turns of the inductance coil *b* which are actually connected in the antenna circuit. A wide variation is not usually necessary or indeed desirable in the large power stations using this type of equipment, as they are ordinarily designed to operate on one particular wave-length. As the electrical characteristics of the apparatus at the sending station may vary, some slight change may be necessary from time to time to keep the station operating on the desired wave-length.

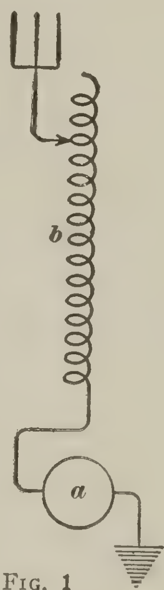


Fig. 1

6. Alternator Coupled to the Antenna.—Inductive coupling of the radio-frequency alternator *a* to the antenna, using an air core transformer, is shown in Fig. 2. This circuit arrangement is practically identical with the preceding one, but is preferable in many cases, as more accurate tuning of the radiating system may be secured by adjustment of the primary winding *b* and the secondary *c*. When it becomes desirable to decrease the radiated energy, the coupling between the coils *b* and *c* is decreased. Detailed connections are not shown in either case, as they vary considerably in the different stations in order to conform with local conditions.

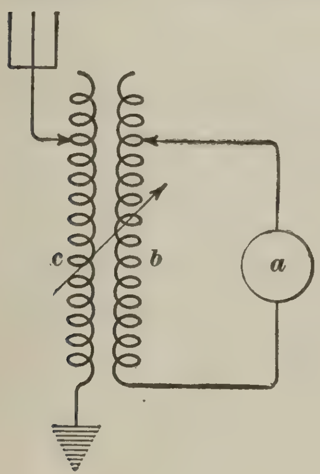


Fig. 2

7. Sending Key.—The key for interrupting the generated wave and producing thereby the required dots and dashes for telegraphic signaling, is preferably connected in the field cir-

cuit of the alternator. The small field current may easily be interrupted, and this, by deenergizing the magnetic circuit intermittently, causes dots and dashes of the code to be produced and ultimately radiated. By using special sending and receiving devices, operation with the Alexanderson alternator has been successfully carried on at speeds up to 200 words per minute.

8. Constant-Speed Motor.—As the wave-length changes to some extent with variation in the frequency, it is important that the alternator's speed be kept constant. In most of the installations the alternator is driven by an electric motor so arranged and controlled as to give a very uniform speed, even when the sending key is being operated. Positive drive is assured through a high-ratio gear connected between the machines so as to run the alternator at a speed several times greater than that of the motor. By this means the speed of the motor may be kept fairly low, and a machine of special design to withstand the terrific speed of the alternator is not required.

OTHER TYPES

9. Other types of alternators with auxiliary apparatus and circuits ingeniously applied have been used in radio communication, but have met with only limited adoption. The circuit arrangements are, in general, very complicated. It is highly probable that with further development some of these machines may be more commonly used, and become active competitors of the alternator just mentioned.

ARC SETS

GENERAL PRINCIPLES

10. The *arc* system for generating high-frequency undamped waves has been used in many stations, with considerable success. This is frequently called the *Poulsen arc*, as it was invented by Valdemar Poulsen. Many refinements have

been added since its original introduction. This device is especially applicable to medium and high-power work, in which fields it finds its greatest usefulness.

DIRECT-CURRENT ARC

11. The fundamental part of an arc set is the electric arc which is instrumental in producing the high-frequency oscillations. When an electron is taken from or added to a neutral atom or molecule, the charged particle thus formed is called an *ion*. This process is known as *ionization*. The particle will have a negative charge if one or more electrons are added to the formerly neutral body, and a positive charge if one or more electrons are removed.

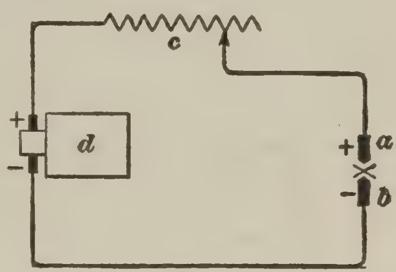


FIG. 3

Ionization may be set up by heat vibration as well as by other means. When the two conducting electrodes *a* and *b*, Fig. 3, are brought together, a current is established, the surface contact heated, and ionization of the air between the electrodes produced. The liberated ions act as carriers of electricity and a current can pass from one electrode to the other even when these are separated a short distance. The high temperature of the arc produces incandescence of the particles of matter in and near the ends of the electrodes and thus a glow of light. The flow of ions produces a current-carrying path of rather low resistance between the electrodes. A large current is prevented by the introduction of the variable resistance *c* between the direct-current generator *d* and the arc.

THE OSCILLATING ARC

12. An arrangement of apparatus that will establish an oscillating arc was developed by Poulsen and consists essentially of a direct-current arc shunted by a tuned oscillating circuit. When the electrodes forming the terminals of the arc are connected to a source of direct current, a high-frequency alternating

current will be established in the oscillating circuit. Fig. 4 shows the fundamental connections of the arc and its shunt circuit. The electrodes, usually of copper and carbon, are shown at *a* and *b*; a variable resistance at *c* and an inductance coil at *d*, both in the generator circuit; an electromagnet in two sections at *e*; a variable condenser at *f*; a variable inductance coil at *g*; and a direct-current generator at *h*. The oscillating circuit consists of the condenser *f* and the inductance coil *g* and forms a shunt across the terminals of the arc.

When a direct current passes between the electrodes, thus forming an arc, a voltmeter connected across the electrodes will indicate a certain voltage. If, with fixed electrodes, the current through the arc is increased, greater ionization of the

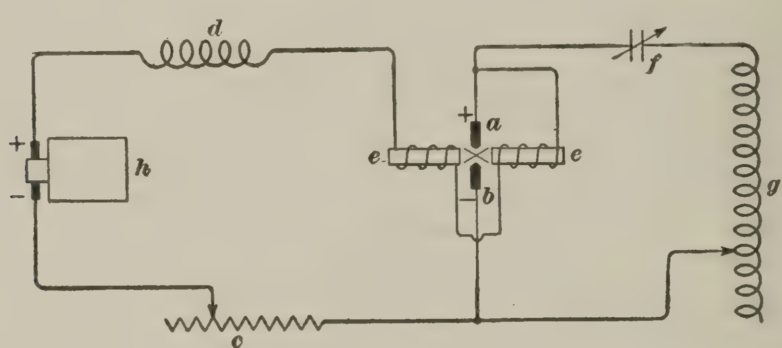


Fig. 4

air is produced, the cross-sectional area of the arc is increased, and the resistance offered to the passage of current reduced to such an extent that the voltage across the electrodes is reduced. If the current through the arc is reduced, the voltage across the electrodes is increased. An inductance coil in a circuit in which the voltage is variable tends to delay changes in the current beyond what would occur with the inductance coil omitted. Both of these effects are important when considering the operation of the oscillating arc.

The arc electrodes are first connected to the generator with the oscillatory circuit disconnected. The electrodes are placed in contact and then separated, thus starting the arc. The oscillatory circuit is then connected to the electrodes. As soon as this circuit is completed, the condenser begins to accumulate

a charge; the left plate being positive since it is connected through coils *e* and *d* to the positive brush of the generator. Since the oscillatory circuit is in shunt with the arc, and the inductance coil *d* in the generator circuit tends to keep the generator current constant, the oscillatory circuit now takes from the arc some of the current that formerly passed through it. The current through the arc decreases, the voltage across the electrodes increases, and this increase in voltage aids in giving the condenser a higher charge than it would otherwise take.

The inductive coil *g* causes the highest point of the charging current in the condenser to take place a short time after the voltage across the electrodes has risen to its maximum value. When the condenser is fully charged no current passes through the oscillatory circuit and the arc carries the normal full current of the generator. The arc voltage resumes its previous value and for a very short interval of time does not vary.

13. Because of the effects just mentioned, the voltage of the condenser rises temporarily to such a value that it is higher than the voltage of the supply circuit. The condenser, therefore, starts to discharge a current through the arc from *a* to *b*, the current established by the condenser being in the opposite direction from that of the charging current. The discharge current through the arc is, therefore, in the same direction as that supplied by the direct-current generator. The current through the arc is increased, the voltage across the electrodes is decreased, and this decrease helps the condenser in sending current through the arc.

The inductance coil *g* in the oscillatory circuit causes the current in the condenser to be prolonged over what it would be if this coil were omitted. The discharge current will, therefore, continue past the point at which it would cease if the circuit had no inductance. As a result, the condenser accumulates a charge opposite in polarity to its former charge; the right-hand plate of the condenser *f* now becomes positive. As the charge of the condenser with its new polarity nears its end, the accompanying current through the arc and the oscillatory circuit

dies out, and with normal conditions restored in the arc, the voltage of the arc rises and resumes its usual value.

The voltage of the condenser under the new conditions discharges a current from *b* to *a*. This discharge current neutralizes part or all of the generator current in the arc; thus raising the voltage across the electrodes. When the oscillating arc is properly tuned, the arc may be temporarily extinguished and the voltage from the generator sends a charging current into the condenser *f* in such direction as to make the left-hand plate positive again. This cycle of charges and discharges takes place continuously and an alternating current of high frequency is, therefore, established in the oscillating circuit.

FACTORS AFFECTING THE FREQUENCY

14. If the discharge current from the condenser is of such value that it is equal to or greater than the arc current, it will stop the current through the arc when the condenser current is equal to and opposes the generator current. When this condition is reached, the whole device is operating properly, and will continue indefinitely to do so. As this operation is dependent upon the values of inductance and capacity in the oscillating circuit, variable condensers and variable inductance coils are commonly installed, so that the circuit may be readily tuned. As soon as the arc is stopped, the supply voltage alone charges the condenser. The charge continues until the condenser has voltage sufficient to break down the arc gap and reestablish the arc. This cycle of events recurs at very frequent intervals and the time during which there is no current through the arc is actually very minute.

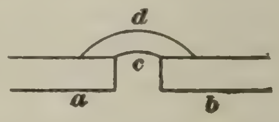


Fig. 5

Fig. 5 represents the two electrodes of the arc at *a* and *b*. The arc may be considered as established along some path between the electrodes, as at *c*, not considering the action of the electromagnets *e*, Fig. 4. When these magnets are energized by current from the generator, the stream of ions is forced to some position as at *d*, Fig. 5. The length of the arc

is very much increased, and hence the magnets can stop, or blow out, the arc quite readily when the current in the oscillating circuit nearly if not entirely neutralizes the normal direct current in the arc. It is very important, in order to obtain a uniformly steady wave, that the arc be broken each time before there is enough voltage to start another one, or at least that the current in the arc be reduced an amount sufficient to cause the oscillating action to be continuous.

15. The operation of the arc, when establishing a radio-frequency current, is largely dependent upon the deionization of the space between the electrodes at an exceedingly rapid rate as soon as the current through the arc dies out. Several methods may be employed to deionize this space, and, when properly applied, the arc will oscillate steadily at a rate of several thousand oscillations per second. The tuning of the oscillating circuit by means of the variable condenser and variable inductance coil is an important factor in determining the frequency of the oscillations.

The flow of ions is affected by a magnetic field. A magnetic flux at right angles to the path of the current in the arc acts to distort the path of the flow of ions. This helps to break the arc and also prevents for the required time the reestablishment of another arc. If the ions were allowed to remain in the space around and between the electrodes, the voltage of the supply circuit might be able to establish another arc before the condenser had stored up a sufficient charge.

16. The chamber surrounding the electrodes is entirely enclosed. Hydrogen gas has been found to assist materially in dispersing the ions of the arc; therefore, a gas containing hydrogen is placed in the chamber. Illuminating gas is often used for this purpose, but as considerable foreign matter is also introduced, the chamber may require frequent cleaning to remove the soot accumulation. Another method which has met with considerable success is the introduction of some substance that contains a large amount of hydrogen. Either kerosene, alcohol, or ether is a suitable material, and the hydrogen is liberated by the intense heat of the arc. Provisions are

usually made for introducing a small amount of liquid into the chamber continuously. Only a very few drops are required from time to time to supply the chamber with a sufficient amount of hydrogen gas.

The positive electrode, also called the anode, is made of copper, and is hollow. Water running through the interior of this electrode keeps it comparatively cool, and prevents it from being rapidly burned up by the intense heat of the arc. The negative electrode, or cathode, is of carbon and its supporting sleeve is frequently water-cooled to keep the temperature down. The cooling of the electrodes helps to disperse the ions and thus to quench the arc. In some cases the electrodes are placed in horizontal positions.

In order that the carbon electrode may be worn away uniformly, a small electric motor geared down to obtain a relatively low speed may be used for rotating the carbon electrode. The gap between the two electrodes may be adjusted by an extension handle, the latter being placed in such a position that it is within easy reach of the operator. In large apparatus the arc chamber is usually water-cooled to remove much of the heat generated by the arc.

17. The electromagnet windings being mounted on iron cores, act as impedance, or choke, coils. Such coils do not offer any opposition to direct current other than that furnished by the resistance of the wire. Their opposition to current at radio-frequency is strong enough to prevent the passage of such a current, and the high-frequency oscillating current established by the arc in the tuned circuit is effectually prevented from passing through the direct-current generator.

The strength of the magnetic field is usually made variable by switches which short-circuit some of the turns. The turns which are short-circuited do not receive any current and, therefore, do not establish a magnetic flux. When the frequency is high, the magnets should be strong in order to remove very rapidly the ions from the vicinity of the electrodes. With a lower frequency there is more time between the successive arcs, and the field strength of the magnets need not be so great.

ARC OSCILLATING CIRCUIT COUPLED TO THE SENDING ANTENNA

18. A method much used in high-power arc stations is shown in Fig. 6, in which the arc oscillating circuit is coupled to the antenna circuit. The high-frequency generating circuit is not unlike the ones which have been described. By means of an air-core transformer, the radio-frequency currents are transferred to the antenna circuit. The capacity of the latter circuit is furnished by the condenser effect of the antenna and ground. The inductance *a* is made variable, so this circuit may be tuned to the wave-length of the oscillating circuit. Where large currents are radiated it is desirable to produce dots and dashes by some means other than actually interrupting the circuit. Key *b* is connected around a few turns of the secondary of the transformer, and short-circuits them when in its

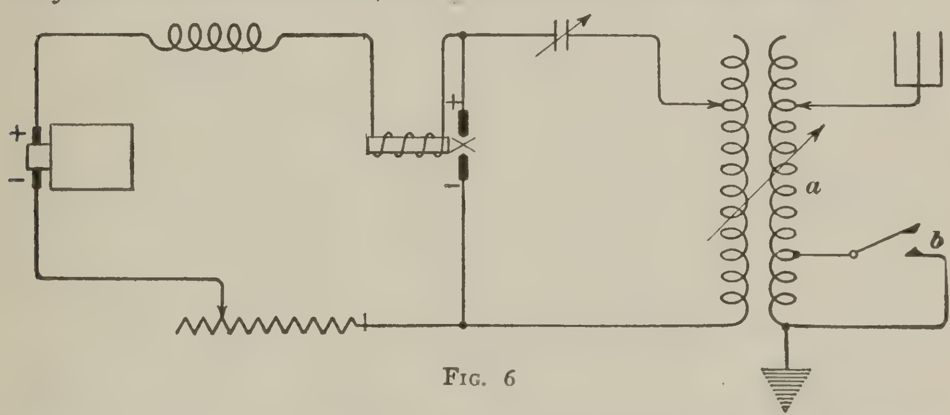


Fig. 6

closed position. The antenna circuit is then tuned to radiate at the desired wave-length, with the key down. When it is open, the aerial circuit is out of tune with the primary winding, and only a portion of the generated energy is transferred to the antenna circuit. What energy is radiated, is at a different wave-length than the one on which communication is established, and does not bother the receiving station. This extra wave is, however, apt to cause interference to other stations which may happen to be operating on wave-lengths near the value of this secondary wave. This system of producing signals is sometimes called the *detuning method*, and is often used in large power stations in which the high-frequency current is established by means other than arc sets.

ARC CONNECTED IN ANTENNA CIRCUIT

19. A method of connecting an arc-set to an antenna where only relatively low power is used, is represented in Fig. 7. The arc is connected directly in the antenna circuit, and the radio-frequency oscillations are established directly therein. As in the preceding case, the capacity in the oscillating circuit is due to the condenser action between the aerial and the ground. The inductance *a* is variable and the length of the radiated wave is determined largely by its setting. The key *b* is connected directly in the ground circuit, which is complete only when the key is down. In order that the arc may operate

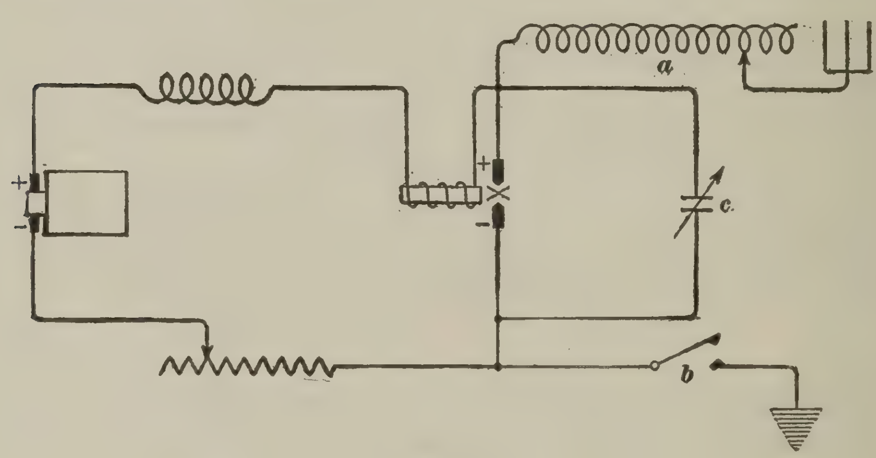


FIG. 7

continuously, it is shunted by a condenser *c*, which serves to maintain the high-frequency oscillations. This condenser helps to boost the strength of the signals when the arc is under normal operation.

Although the arc is operating all the time, energy is radiated only when the key *b* is closed. The key could be connected so as to short-circuit some of the turns of the inductance instead of opening the ground connection. Tuning should then be made so that the correct wave-length would be radiated with the key closed. Nearly full power would be radiated with the key either open or closed, and the arc would be in continuous operation. Under this condition no shunt condenser *c* would be required.

ELECTRON TUBES

GENERAL CONSIDERATIONS

20. Electron tubes are used in the production of continuous, or undamped, currents at radio frequency. The tubes are particularly useful in the transmission circuits of low-power stations rather than in similar circuits of high-power stations. The same type of tube may be used in either transmitting or receiving circuits, but special tubes have been developed for transmitting circuits that operate at higher efficiencies than the tubes of more general application. The principles underlying the operation of electron tubes when used as generators of oscillating currents were treated in a previous Section.

ELEMENTARY CIRCUIT ARRANGEMENTS

21. In Fig. 8 coil *a* is in the plate circuit, the inductance coil *b* is in the antenna circuit, and coil *c* is in the grid circuit. If the coils *a* and *c* of the elementary oscillating electron-tube circuit are coupled to the antenna coil *b* in the manner indicated, a radio-frequency current will be established in the antenna circuit. A small oscillation produced in the grid circuit will produce a greater change of current in the plate circuit, including the coil *a*. This coil being coupled to the inductance coil *b* produces oscillations in the coil *b* which react upon coil *c* in the grid circuit. The feed-back then serves further to amplify or increase

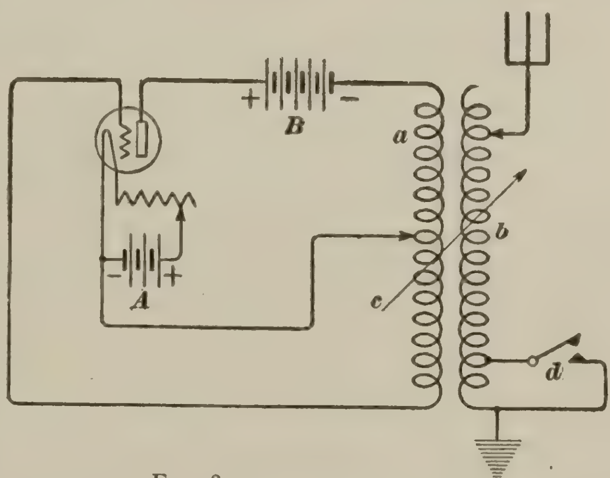


Fig. 8

the oscillations in the antenna circuit and to maintain them when once started.

As only the antenna circuit is a tuned circuit, and oscillating at the desired radio frequency, the radiated wave is very sharp. The frequency of the alternating current finally established depends primarily upon the tuning of the antenna circuit, although it is important that the coupling between the antenna coil *b* and the other coils *a* and *c* should be adjusted for the desired amount of energy transfer.

A key located as at *d*, may be used to send telegraphic code signals. The antenna is tuned to radiate signals of the desired wave-length with the key closed. Opening the sending key introduces a few additional turns into the antenna circuit, and energy is radiated but on a different wave-length. Operation seems to be best with this arrangement, although some interference is produced by the useless radiated energy. The key may be so located as to interrupt the antenna current, by opening the circuit, in which case good results may be expected. Placing the key in some part of the tube circuits is not satisfactory, as the action is sluggish and the radiated wave is apt to be ragged.

This system of producing radio signals is usually employed in low-power sets, as there is a definite limit to the amount of energy which may be transferred through the ordinary tube. Several tubes, however, may be connected to operate in parallel where large power output is desired, but the excessive cost of this expedient is generally prohibitive. Large capacity tubes have been developed for use in high-power stations.

COUPLED OSCILLATING CIRCUIT

22. A somewhat different circuit arrangement using an electron tube as an oscillator to produce undamped waves is indicated in Fig. 9. A fundamental requirement for the successful operation of this circuit is that the coupling between coils *a* and *b* must be quite close, that is, the coils must be brought close together, so that a large amount of the energy in the plate circuit is fed back to the grid circuit. When the varying electromotive force obtained from coil *b* is more than

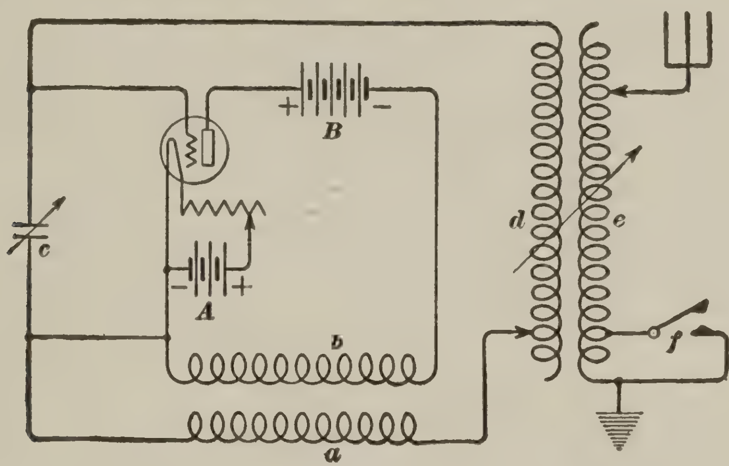


FIG. 9

enough to sustain oscillations in the oscillating circuit *a*, *c*, *d*, this circuit may be used as a source of sustained waves.

23. As the principle of operation of the oscillating circuit is somewhat different from the one just described, it will be explained briefly. The instant all the circuits are closed, starting with no voltage on the grid, there will be a current in the plate circuit which starts at zero and increases. The current through coil *b* induces an electromotive force in coil *a* such that one of its terminals is positive, and the other terminal is negative. The positive terminal being connected to the grid places a positive voltage on the grid which causes the current in the plate circuit to increase at a still faster rate. This increasing action is cumulative, and would continue

indefinitely were there not some factors to limit it. In this case a limit is reached when the quantity of negative charges, or electrons, flowing in the tube from filament to plate becomes so great that a larger number cannot flow. This is the phenomenon described as *saturation* of the tube.

As the limiting point is approached, the increase in the current in the plate circuit becomes less rapid, a condition which causes the voltage at the terminals of coil *a* to decrease and a smaller electromotive force will be applied to the grid. A point is then reached where there is no further increase in the current in the plate circuit. At this instant, with a steady current through coil *b*, there will be no voltage induced in coil *a* and consequently none applied to the grid. The current in the plate circuit then decreases in order to come down to its normal value for zero grid voltage.

With a decreasing current through coil *b*, there will be an electromotive force induced in coil *a*, which is in a direction opposite to that induced when the current in coil *b* was increasing, that is, the terminal which was positive is now negative and the other terminal is positive. The negative voltage applied to the grid causes the current in the plate circuit to be decreased at an increasingly faster rate, this in turn causing a still greater negative voltage to be applied to the grid. This decreasing action tends to continue indefinitely, but a limit is reached when the plate current reaches zero. Therefore, as the limiting point is approached, the decrease in the current in the plate circuit becomes less rapid, which causes the voltage induced in coil *a* to decrease, and a smaller electromotive force to be applied to the grid. A point is then reached when there is no further decrease in the current in the plate circuit, the grid then being at zero voltage. The current then increases in order to reach its normal value at zero grid voltage.

24. A complete cycle of changes of current in the oscillating circuit has been completed and the action continues during the operation of the tube. Thus, there is a voltage at the terminals of coil *a* which is continuously oscillating between positive and negative values. The coil *a* is included in the circuit

a, *c*, *d*; therefore, there is an oscillating current set up in this circuit whose frequency depends upon the amount of inductance and capacity in the circuit; that is, the frequency depends upon the inductance and capacity properties of *a*, *c*, and *d*.

All that is necessary to use this arrangement for transmitting sustained wave signals is to couple coil *d* to a coil *e* forming part of an antenna circuit. A transmitting key could be located as shown at *f* to interrupt the signals sent out on the desired wave-length, into intelligible dots and dashes of the telegraphic code.

GENERATOR IN PLATE CIRCUIT

25. Another complete circuit arrangement for transmitting undamped waves by means of an electron tube is indicated in Fig. 10. As in other cases, the plate circuit is coupled to the grid circuit through coils *a* and *b*, and supplies the latter with

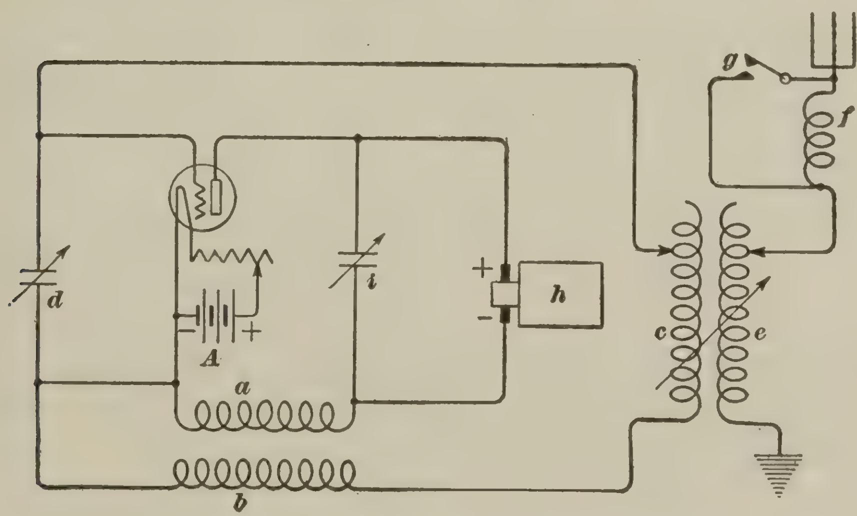


FIG. 10

energy. The oscillating circuit consisting of *b*, *c*, and *d*, is coupled to the antenna coil *e*, producing undamped oscillations therein. The coil *f*, which is short-circuited by a sending key *g*, is represented as being separate from coil *e*, although this is

not always the case, it being feasible to have the sending key short-circuit a few turns of any coil in the antenna circuit.

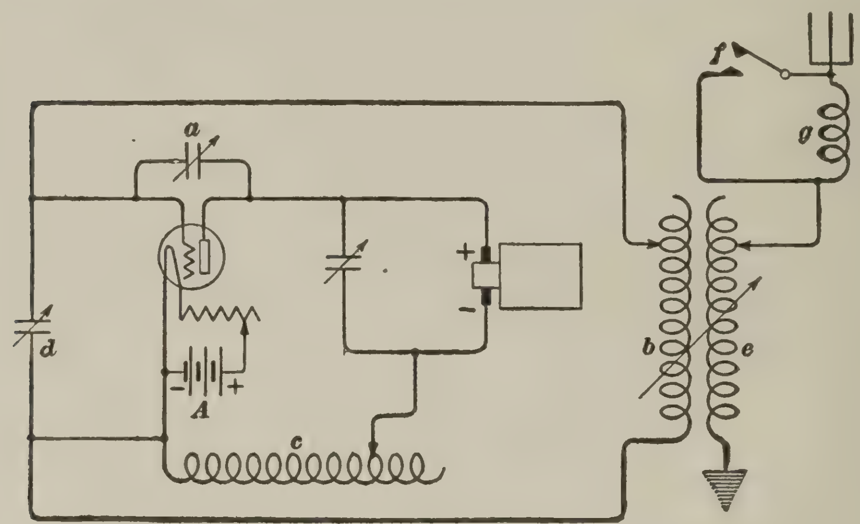


FIG. 11

26. A small direct-current generator h is used in place of a B battery, for the reason that a much higher voltage is necessary in the plate circuit of an electron tube used for transmitting than is required in the plate circuit of one used for receiving. A generator is usually a better device than a battery to provide a high electromotive force. The condenser i, shown connected in parallel with the generator, is for the purpose of providing a good path around the generator for the rapidly pulsating current in the plate circuit, as the generator windings offer high opposition to the pulsating current. The production of a greater amount of power may be secured by connecting two or more tubes in parallel;

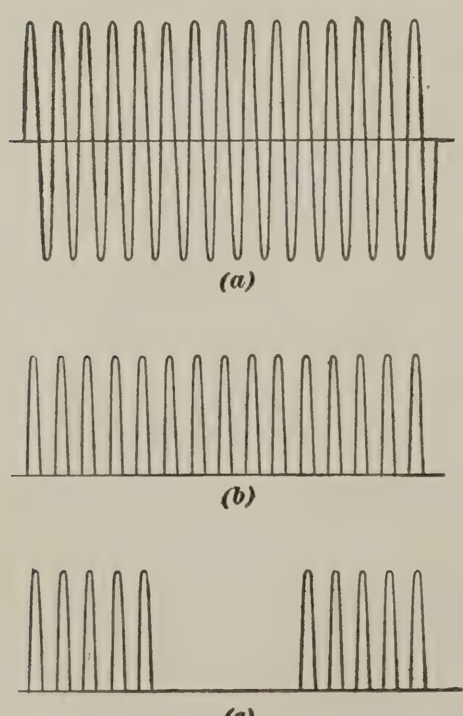


FIG. 12

that is, all the grid terminals would be connected to a common terminal, and all the plate terminals, to a common terminal, and then these common points would be connected in the circuit just as if they were the terminals of a single tube. The filament terminals are also connected in parallel with a separate control resistance in each filament circuit, so that the filament current of each tube may be accurately adjusted to its best operating value. This will help compensate for any differences in the operating characteristics of the tubes. It has not been found satisfactory to connect the filaments of tubes in series, especially power tubes, as the plate current of some of the tubes may cause a larger current in the filament circuit of some tubes. This would be due to the combination of the plate current with the filament current, which, in power tubes is fairly large when compared with the filament current.

27. Another distinctive type of connection is indicated in Fig. 11. Here the plate circuit is coupled to the grid circuit by means of a condenser *a* instead of by inductance coils. The condenser acts, as did the coils of previous cases, to transfer some of the plate-circuit energy back to the grid circuit. The frequency of the oscillations depends on the values of the inductances *b* and *c*, and capacities *a* and *d*. As before, energy is transferred to the antenna by means of inductance coils *b* and *e* which are coupled together. A key *f* is shown arranged to short-circuit a small coil *g* consisting of a number of turns connected in the antenna circuit.

RECEIVING TELEGRAPH SIGNALS

FUNDAMENTAL PRINCIPLES

28. In order to be effective in radio communications, the radiated waves should have a frequency above 20,000 cycles. Undamped waves are a continuous series of these high-frequency waves, as shown by view (*a*) in Fig. 12. If undamped waves at this frequency were sent through a telephone receiver, they would not produce a sound, as the mechanical features

of the receiver would prevent its response, or vibration of the diaphragm, at this tremendous rate. The circuit arrangement entirely suitable to the reception of damped waves will not be affected by undamped-wave, radio-telegraph signals, and other circuits and devices must be employed, or, in some cases, merely combined with the damped-wave receiving set.

CIRCUIT INTERRUPTING DEVICES

BUZZER

29. One method of receiving and detecting sustained waves is indicated in Fig. 13. Here the arrangement of circuits is exactly the same as for receiving damped-wave signals, except that a circuit-interrupting device *a* has been inserted in series with the detector *b* and telephone receivers *c*. The interrupter forms part of an electric buzzer *d*, whose operating circuit is also shown connected to its own local battery *e*. The buzzer operates at its normal audio frequency, and the vibrating armature periodically opens and closes the circuit through the detector *b* and telephone receivers *c*.

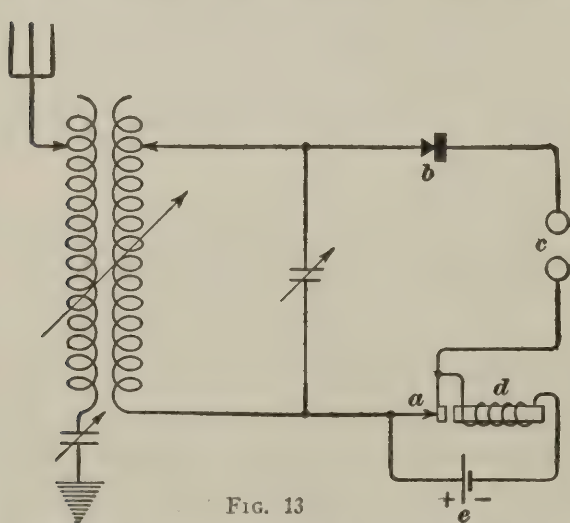


Fig. 13

The action of breaking the circuit cuts up the received radio-frequency waves into groups of a few high-frequency oscillations, with quiet intervals separating the periods during which current is passing in the circuit. As has been explained, a detector rectifies any alternating-current wave passing through it, and would in this case pass a pulsating current through its circuit similar to that represented in view (*b*), Fig. 12, were it not for the buzzer. As the cir-

cuit is opened at intervals by the buzzer, the rectified pulsations of current that remain will be grouped somewhat after the manner shown in view (*c*). These grouped current pulsations passing through the coils of the telephone receivers will act upon their diaphragms, for, although the individual pulsations are at a high frequency, they are all in one direction, and thus their combined action is to hold the diaphragms in their active positions during each group of pulsations. The diaphragms will resume their normal positions during the intervals between wave-trains. These groups of pulsations occurring at audio frequency give audible signals, a long series of groups representing a dash, and a short series of groups representing a dot in the telegraphic code.

CHOPPER

30. Undamped waves may be received by connecting a *chopper* in the detector and receiver circuit of a damped-wave

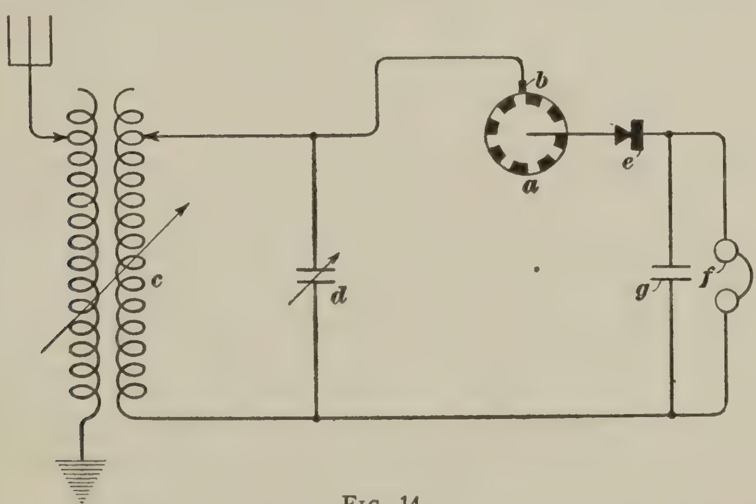


FIG. 14

receiving set. This will result in the circuit arrangement indicated in Fig. 14. The chopper normally consists of a toothed wheel *a*, and a brush or contact point *b* which touches the teeth momentarily as they pass. A motor rotates the toothed wheel at a fair rate of speed, and the teeth make brief periodical contact with the brush *b*. During the period of contact, the oscillating circuit, consisting of the inductance *c* and

the condenser *d*, is connected to the circuit through the detector *e* and the telephone receivers *f* just as in a damped-wave set. As was the case there, a small condenser shunting the telephone receivers, as at *g*, may be used to smooth out and assist in receiving the high-frequency pulsations.

Here as in other continuous-wave systems, the oscillating circuit receives undamped radio-frequency signals. As long as the teeth of *a* do not touch the brush *b* the receiver circuit is open and no signal is heard. When the contact points close the receiver and detector circuit a few cycles of radio-frequency current are allowed to pass from the oscillating circuit. However, the detector performs its rectifying action and allows only a pulsating current to pass through the telephone receivers. These few pulsations of current, which pass during the contact period, produce one click in the telephone receivers. The frequency of the opening and closure of the detector and receiver circuit, and, consequently, the tone of the received signal may be controlled to a large extent by regulating the speed of the chopper wheel. The note produced by the telephone receivers is not quite as uniform nor as easy to receive as in some other receiving systems.

TIKKER

31. The *tikker* depends upon a make-and-break contact to produce audible signals from undamped waves. In one form it uses the circuit of Fig. 15, which is quite similar to that of Fig. 14. A grooved wheel *a*, Fig. 15, forms one side of the contact and is rotated by a motor. A spring *b* presses into the groove of wheel *a* and makes a sliding and imperfect contact. The minute irregularities in the wheel open and close the contact very frequently, producing a series of breaks between the oscillating circuit and the detector and receiver circuit very similar to that of the chopper. A small condenser *c* shunting the telephone receivers *d* will help in the reception of the high-frequency impulses.

In the reception of high-frequency signals corresponding to the shorter wave-lengths, it seems desirable to use the detector

indicated at *e*. On the lower frequencies, it is quite feasible to eliminate the detector, but a much larger condenser must be used at *c*. The rotation of the wheel *a* must also be increased, and this increase will cause a more frequent closure and opening of its circuit. The inductance *f* and condenser *g* store up considerable energy while the receiver and condenser circuit is open at the tikker. This energy is instantly trans-

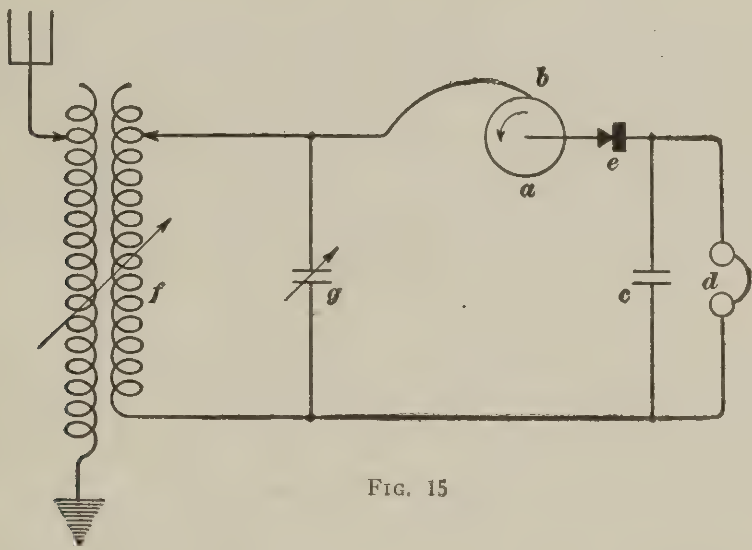


Fig. 15

ferred in bulk to the large condenser *c* while the tikker contact is closed. This contact opens in time to prevent condenser *c* from discharging back through the oscillating circuit, and the charge is therefore expended in producing a click in the telephone receivers. The irregular contact of the tikker and the consequent non-uniform charges on condenser *c*, produces a tone neither uniform nor musical. More pronounced makes and breaks are obtained by rotating the wheel against the contact point, as shown by the arrow in the figure.

BEAT CURRENTS

PRINCIPLE OF OPERATION

32. Two undamped-current waves of different frequencies are indicated in Fig. 16 (*a*) and (*b*). When these two waves are combined into one wave by adding the instantaneous values of the two separate waves, taking into consideration their positive and negative relations, the resulting wave will be similar in form to that shown in view (*c*). This wave is an

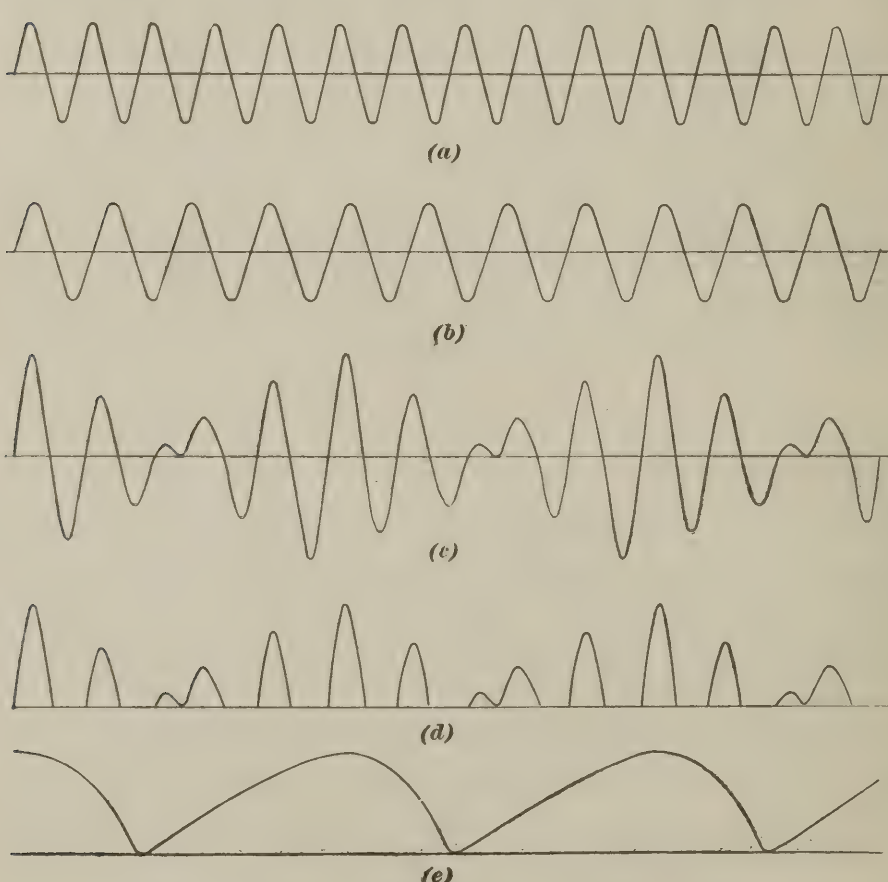


FIG. 16

indication of what is known as a *beat current*. The amplitudes of the individual alternations of the beat current are not uniform. Periodical increases and decreases of amplitude are formed by the addition of the two separate waves. Maxi-

mum points are due to the addition of two simultaneous maximum values in the same direction, and minimum points are due to two simultaneous zero values or to the addition of two simultaneous maximum values, one of which is positive and the other negative. The amplitudes of the waves between the maximum and the minimum points depend upon the simultaneous individual values and their positive or negative relations.

The time between any two maximum points on the beat-current wave is much longer than the time occupied by one cycle of either of the two separate waves. The beat current when rectified, view (*d*), and further modified by the action of the telephone receivers and their condenser produces a periodic current of audio frequency, view (*e*).

HETERODYNE RECEPTION

33. Alternating-Current Generator.—The *heterodyne* method of receiving depends on the principle of superimposing upon the incoming undamped high-frequency wave a similar wave of a slightly different frequency. Fig. 17 shows

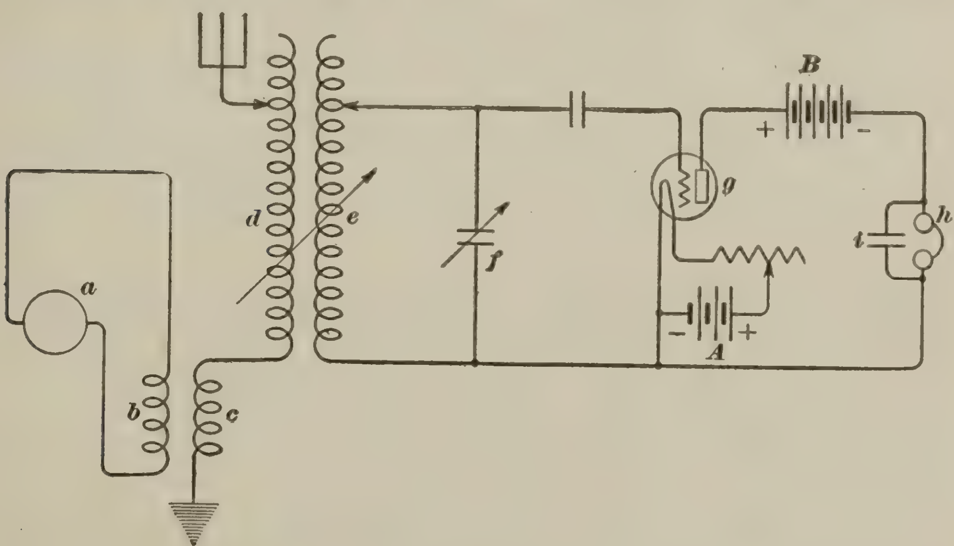


FIG. 17

one arrangement of circuits for heterodyne reception. A small alternating-current generator is shown at *a*. The primary

coil b and the secondary coil c of a transformer serve to couple the generator and antenna circuits.

Suppose the incoming high-frequency current to be that represented by Fig. 16 (a) and the alternating current of another frequency supplied to the antenna circuit by the generator to be that shown in view (b), then the combined current, or beat current, in the antenna circuit may be indicated by view (c). The beat current in coil d, Fig. 17, produces a current of similar wave shape in the oscillating circuit consisting of the secondary coil e and the condenser f. The electron tube g rectifies the beat current, Fig. 16 (c), into the form shown in view (d). The current represented by view (d) is seen to be made up of high-frequency pulsations of current, but divided into beats or groups by their large and small amplitudes. This rectified current in the plate circuit of tube g, Fig. 17, operates the telephone receivers h, and also charges the shunt condenser i during the time of each short series of high-frequency current pulsations, or with each beat. The shunt condenser helps to smooth out the rapid pulsations impressed on the telephone receivers, causing the current to assume the general form shown in Fig. 16 (e), and this current produces a click in the receivers for each pulsation of the beat current. The diaphragms of the telephone receivers will not act quickly enough to respond to the individual radio-frequency pulsations, but will produce audible sounds when a current represented by the audio-frequency wave, view (e), passes through the coils of the telephone receivers.

34. The beat frequency depends directly upon the difference between the frequencies of the component waves; that is, if there is very little difference between the received and applied frequencies, the beat frequency will be low, while, if there is a large difference, the beat frequency will be high. The frequency of the received wave is, therefore, fixed for any given conditions, but by varying the frequency of the local applied current, the beat frequency may readily be controlled. In this manner sharp tuning is possible, and many interfering stations may be easily tuned out. It should be

noted that a crystal detector or some other form of rectifier might be used in place of the electron tube; the action of the tube in this arrangement being simply to rectify the beat current caused by the interference of the two high-frequency oscillations.

To supply this current, the alternator for generating the local oscillations might just as well be connected to the local oscillating circuit, through coil *e*, Fig. 17, as to the antenna circuit. The principle of operation would remain the same as previously described. This method of receiving signals tends to amplify the signals or make them stronger, as the local energy is added to the incoming signals to produce the effective beat current. The coupling between coils *b* and *c* should be of such value as to induce a current in the antenna about equal to that received from the sending station.

The beat and consequent audio frequency current pulsations of Fig. 16, will be received only while both of the component high-frequency currents are established. The antenna, Fig. 17, will receive its high-frequency current from the sending station only while that station is sending out the dot-and-dash signals. During the intervals or spaces between these elements of the signals there will be only the locally generated high-frequency current in the receiving set. This radio-frequency current is, however, unable to produce any audible signals of itself and is used up in the receiving set as waste energy. It is also important that the local oscillating current be established before the incoming signals can be received.

35. Electron-Tube Generator.—The heterodyne method of receiving undamped radio signals may be used with an electron tube acting as a generator. Fig. 18 shows such an arrangement in which tube *a* and its associated circuits act as the generator of a radio-frequency current. Through the action of the transformer coils *b* and *c*, this current is transferred to the antenna circuit where it is combined with the current of the incoming wave to form a beat current. The receiving circuit including the electron tube *d* is of the type commonly employed for damped waves. The signals reaching

the tube *d* are carried by the beat current. The tube rectifies the beat current and the rectified current operates the telephone receivers *e*.

AUTODYNE RECEPTION

36. Instead of using two tubes as in the preceding case, one electron tube may be used to perform the complete operation of receiving and detecting the incoming undamped radio-frequency oscillations. This is known as the *autodyne* method, which, briefly stated, is the system of using one tube to function as a generator of high-frequency current oscillations as well as to function as a rectifier for the beat current.

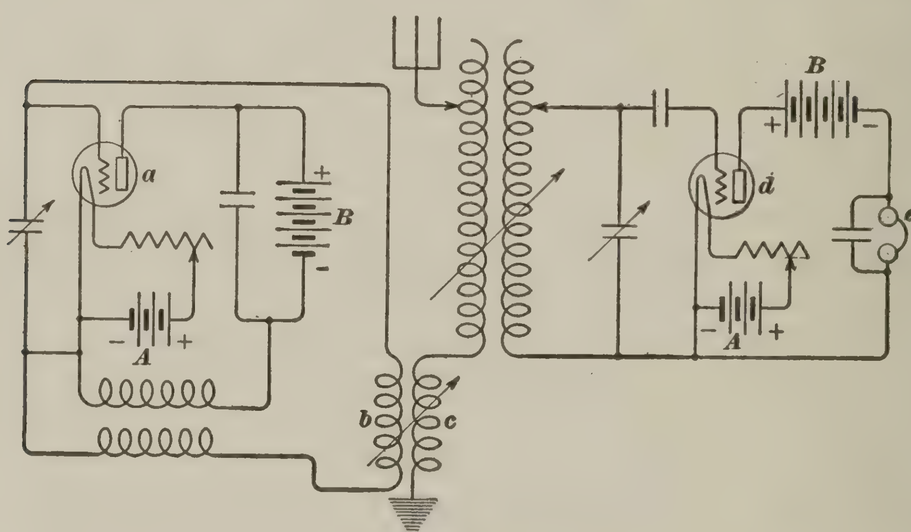


FIG. 18

Fig. 19 shows a circuit diagram based on the autodyne method. The pulsating current of the plate circuit is transferred by the feed-back method to the oscillating circuit through the action of coils *a* and *b*. The coupling between these coils should be rather close for successful operation, and the various adjustments in the coupled circuit must be accurately made. In other respects the principle of operation is not unlike the heterodyne method of reception.

The signals as received by an antenna are at best very weak, hence the amount of energy required to produce local oscilla-

tions of equal strength is consequently small. It is important when using the heterodyne method of reception, that a local current of approximately equal amplitude be combined with the incoming antenna current. This is also applicable to the autodyne method of reception, but as the oscillating current is necessarily small in this case, it is not apt to need special attention.

In the autodyne circuit the three-element electron tube is exhibiting three of its important functions, namely, those of acting as oscillator, detector, and to some extent as an amplifier, and these all simultaneously. The principle of feeding

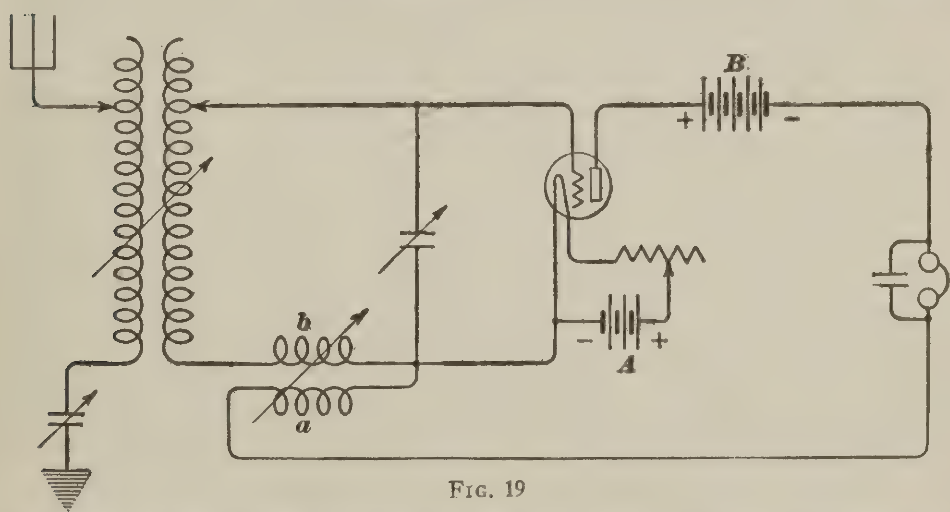


Fig. 19

some of the plate current back to the grid could probably be applied with advantage to other circuits using the three-element tube, especially those using one or more stages of radio-frequency amplification.

In the circuit of Fig. 19, as well as in others of a similar nature, the location of the *B* battery and telephone receivers could be interchanged with perhaps an improvement in operation. As the plate circuit carries a radio-frequency current, part of which is fed into the grid circuit, it is very probable that an improvement in operation will be secured by shunting the *B* battery by a condenser. This will provide a good path for the radio-frequency oscillations to the grid. A like result could be accomplished by connecting the condenser shunting the telephone receivers so as to include the *B* battery.

RADIO TELEPHONY

PRINCIPLES OF OPERATION

37. Radio telephony is the transmission of speech or other intelligible sounds by means of radio waves. In wire telephony the current-carrying medium is a metal conductor, while in radio telephony there is no visible connection between communicating stations. The electric waves in both wire and radio telephony are changed into audible sounds by means of suitable receiving apparatus; the sounds heard at the telephone receiver correspond with those at the transmitter in the sending station.

In radio telephony changes in the resistance of a circuit caused by sound waves striking the diaphragm of a transmitter in that circuit are used to modify the amplitude of the oscillations of a radio-frequency current. These modified oscillations are transmitted from station to station and by the aid of suitable apparatus at the receiving station, telephone receivers reproduce the sounds made at the transmitting station.

38. Modulation is the act of varying the amplitude of radio-frequency oscillations by the action of the audio-frequency changes established by the transmitter. In undamped-wave radio telegraphy, the outgoing oscillations are either interrupted or else detuned enough to produce dots and dashes of the telegraphic code. The outgoing oscillations in radio telephony are merely modulated or their outlines changed to correspond with the original sound disturbances.

Three methods for producing undamped waves of radio frequency, namely, by the use of the alternator, the arc, and the electron-tube oscillator, have been described, and any one of these may be employed for producing the radio-frequency carrier current. Only one typical arrangement will be illustrated and described for each of two of the systems.

39. Fig. 20 (*a*) represents an undamped wave of radio-frequency current such as would be produced by any of the devices just mentioned. View (*b*) represents approximately,

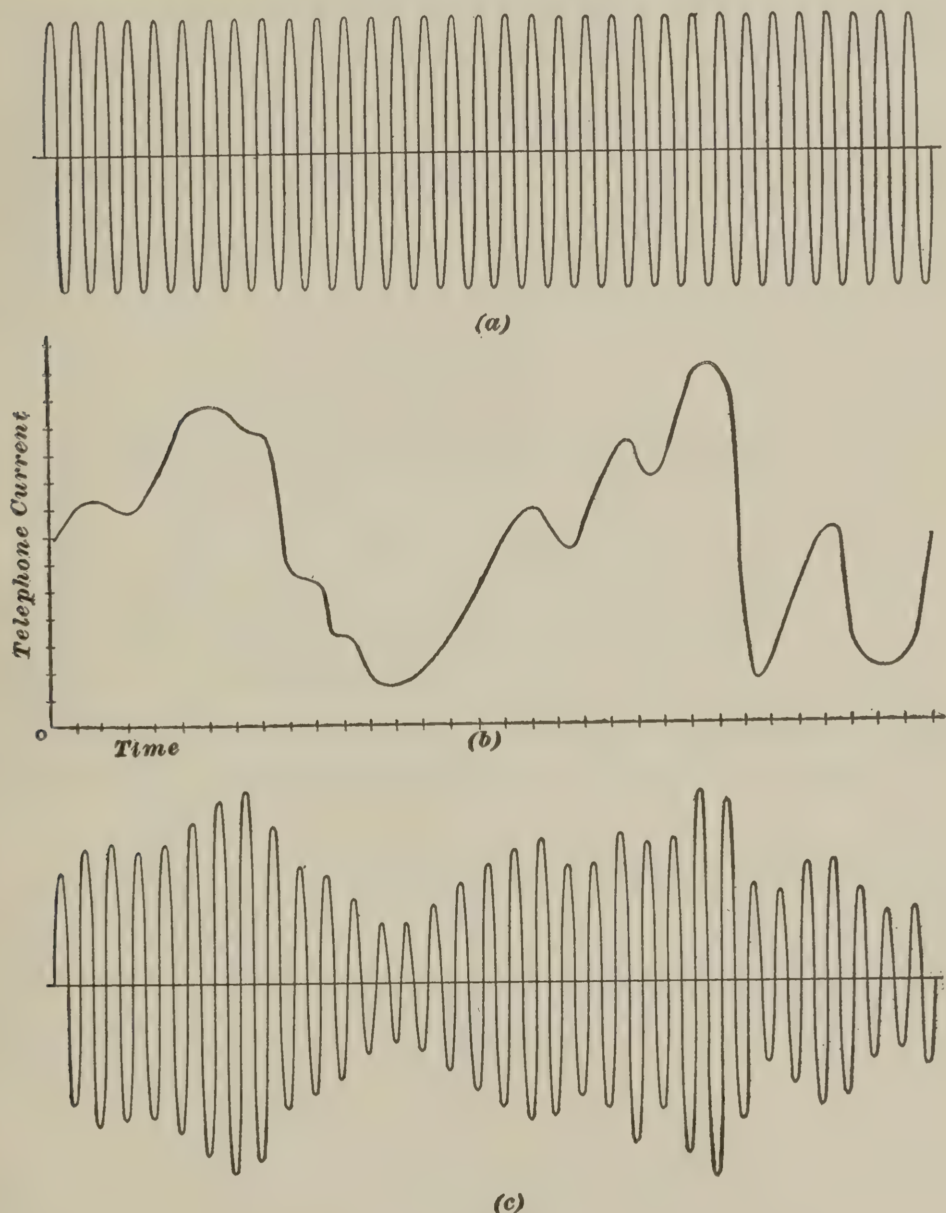


Fig. 20

the variation in current in a circuit consisting of a transmitter in action, a battery, and connecting wires. The current waves, view (*b*), as produced by the human voice are, in general, of irregular form. When the oscillations, view (*a*), are modi-

fied, by methods explained later, the outline of the modulated radio-frequency wave thus formed, view (*c*), assumes the general wave shape of the audio-frequency wave shown in view (*b*), but the high-frequency oscillations with modified amplitudes are still retained.

The undamped radio-frequency current, view (*a*), before modulation is sometimes called a *carrier current*, but the modulated radio-frequency current is the one actually transmitted. Its frequency is high enough to produce radio disturbances in the ether which will carry well and thus render communication over long distances possible.

TRANSMITTING CIRCUIT CONNECTIONS

ARC GENERATOR

40. Circuit arrangements for transmitting radio telephone signals or messages differ from those used in sending out undamped-wave radio telegraph intelligence in this respect, that the sending key used in producing dots and dashes of the telegraph code is replaced by a suitable device for modu-

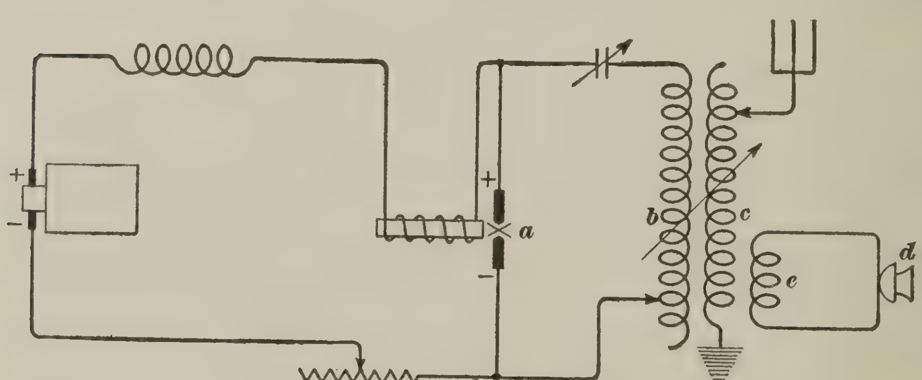


FIG. 21

lating the carrier current. The arc set *a* shown in Fig. 21, operates in the usual manner to produce undamped waves of radio-frequency. These oscillations in the inductance coil *b* are transferred by induction to coil *c* in the antenna circuit. An ordinary telephone transmitter *d*, when spoken into, produces

variations in the resistance of its local circuit in accord with the changes in the sound waves impressed upon the diaphragm.

The inductance in the direct-current circuit supplying the arc tends to maintain the high-frequency current in the coil *c* as well as that in the other portions of the antenna circuit at nearly constant values when the transmitter is inactive. The telephone transmitter circuit is coupled to coil *c* by coil *e* and, therefore, even when the transmitter is inactive takes away a very small amount of the energy supplied to coil *c* by coil *b*. The amount of the energy taken by the telephone transmitter circuit depends on the resistance of this circuit. When the transmitter is active, the resistance of its circuit is varied and a variable amount of energy is supplied to it by coil *c*. Most of the remaining energy of coil *c* is radiated from the antenna circuit to the ether and the amount radiated is variable because of the variable amount of energy absorbed from coil *c* by the telephone-transmitter circuit. The amplitude of the radio-frequency oscillations is decreased when the amount of energy absorbed is increased and the amplitude of the oscillations is increased when the amount of energy absorbed is decreased. The energy radiated to the ether is thus modulated in accordance with the sound waves impressed on the transmitter diaphragm.

The arc set shown in Fig. 21 is merely one type of oscillator, and is often used in radio-telephone transmission. In place of the arc-generator set, however, a high-frequency alternator may be used, but an electron-tube oscillator is more commonly used than the two methods just mentioned for producing a high-frequency carrier current.

41. Although the transmitter circuit, Fig. 21, is shown coupled to the antenna circuit, such is not always the case. In practice, the transmitter may be coupled to other parts of the oscillating circuit, or even connected directly in series at certain places. For instance, a large current-carrying transmitter might be included in the antenna circuit, or several transmitters of the usual type could be connected in parallel in the same part of the circuit. Successful modulation has

been accomplished by connecting the transmitter in the supply circuit, as, for example, in the field circuit of the Alexanderson alternator. As the current variations produced by the ordinary type of transmitter are often quite small, an amplifier is sometimes used to strengthen the variations before they are combined with the carrier current. It is impracticable to consider all the possible ways in which the audio-frequency waves are actually impressed on the carrier current. The fundamental principle to be applied is that the audio- and radio-frequency currents must act to form a radio-frequency current which carries the characteristics of the original sound wave; the exact method by which this is accomplished is unimportant, so far as the radiated wave is concerned.

USE OF ELECTRON TUBES

42. The electron tube, aside from its other important uses, is an excellent device for the absorption of energy. It is sometimes used in this connection in radio telegraphy, but the

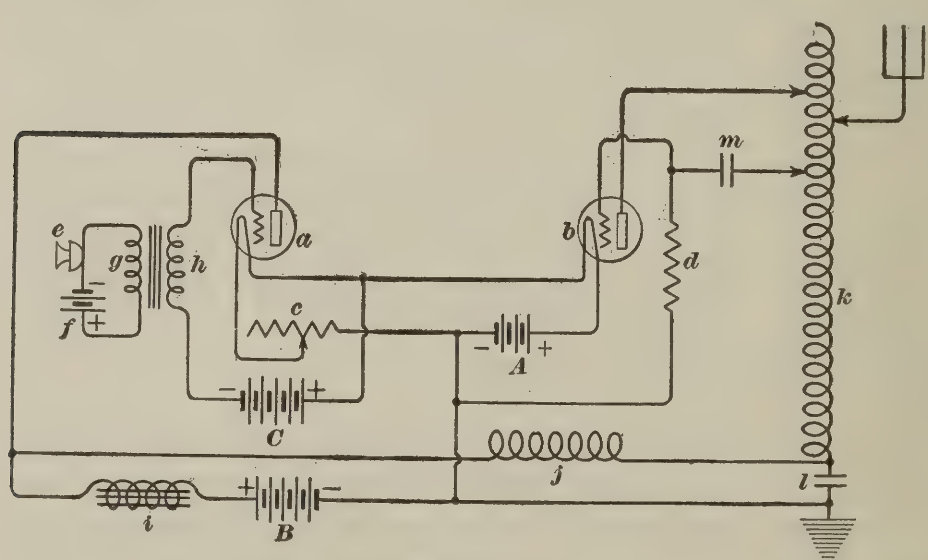


Fig. 22

more common case is in radio telephony to modulate the radio-frequency current generated by an oscillating tube. In the circuit of Fig. 22, the modulator tube *a* controls the plate

current of the oscillating tube *b*. The filaments of the similar three-element electron tubes are connected in series, and supplied with current from a common *A* battery, which is controlled by an adjustable rheostat *c*. Likewise a common *B* battery furnishes a voltage for both plates in parallel. A *C* battery in the grid circuit of the modulator tube places a negative electromotive force on the grid. A slightly negative voltage is given to the grid of the oscillator tube *b* by the connection through a high resistance *d* to the negative terminal of the *B* battery. These negative voltages have been found necessary in order to force the tubes to operate steadily, and without distorting the signals. This is a very important feature in clear radio telephony.

A transmitter *e* with a local battery *f* is included in the circuit of the primary *g* of a transformer, whose secondary is at *h*. It is well to keep in mind the important fact that the electron flow is from the filament to the plate, while the plate current is assumed to be in just the opposite direction. The current from the positive terminal of the *B* battery passes through an inductance coil *i*, and then divides and passes to the two plates. The inductance coil *i* which has an iron core to increase its effect, maintains the current through itself practically constant.

A very irregular pulsating current is produced in the transmitter circuit when the diaphragm intercepts sound waves. By transformer action these pulsations are transferred to coil *h*, and then to the grid of the modulator tube *a*. If the effect of the voltage generated in the secondary coil *h* by the action of the transmitter is, at a given instant, such as to decrease the negative charge on the grid as compared to its condition when the transmitter was inactive, the plate current in the modulator tube will be increased because of the lessened opposing action of the negatively charged grid. The flow of electrons is thereby increased, therefore, the plate current is increased. The *B* battery furnishes a nearly constant current and if the plate current of tube *a* is increased, less current can pass to the plate circuit of the oscillator tube *b*. The plate circuit of the oscillator tube is connected to the antenna circuit and when the plate

current is decreased, the amplitude of the radio-frequency oscillations radiated by the antenna is decreased.

43. If the action of the transmitter circuit, is, at a given instant, to increase the negative charge on the grid of the modulator tube *a*, the opposing action of the grid will be increased, the flow of electrons decreased, and, therefore, the plate current of tube *a* decreased. Because of the nearly constant current supplied by the *B* battery, more current will pass to the plate circuit of the oscillator tube *b*, and the amplitude of the radiated oscillations will be increased.

It is convenient to consider the variations of the grid voltage of the modulator tube as changing the resistance of the path between the plate and the filament in the tube. This change in the resistance causes a change in the division of current supplied to tubes *a* and *b* from the *B* battery.

It should be noted that any sound intercepted by the transmitter does not alter the frequency of, but modulates the outline of the radio-frequency oscillations. The modulation of the wave preserves the general characteristics of the original sound impressed on the transmitter.

44. The action of the inductance coil *i* prevents the audio-frequency plate-current pulsations of tube *a* from passing into the *B* battery, hence they follow the path through coil *j* to the plate of the oscillating tube. The coil *j*, which has less inductance than coil *i*, offers very little impedance or opposition to the audio-frequency variations, but quite effectually prevents the radio-frequency currents from leaving the antenna circuit, and becoming lost. The antenna coil *k* is equipped with several adjustable contacts. Tuning of the antenna proper is made by varying the contact of the movable antenna terminal. The series antenna condenser *l* may also be made variable for adjustments on short wave-lengths. Portions of coil *k* are used in conjunction with condenser *l* to form the oscillating circuit of the generator tube *b*. The grid of tube *b* in connection with the other portions of the oscillator-tube circuit enables the tube to establish a radio-frequency current. Condenser *m* prevents a shunt circuit for direct current between *d* and *k*,

which are connected to opposite terminals of the *B* battery, but allows an oscillating current from the antenna inductance coil *k* to pass to the grid of tube *b*.

RECEIVING CIRCUITS

45. As was shown by view (*c*) of Fig. 20, the outline of the radiated wave corresponds to a large extent with the original sound wave. If the current is passed through a rectifier at the receiving station, one-half of the energy will be prevented from passing through the telephone receivers, and a pulsating current will result. The radio-frequency carrier current will be vibrating too fast to affect the telephone receivers. The audio-frequency pulsations, however, act upon the telephone receivers and accurately reproduce the original sound, with its characteristics practically unchanged.

46. It will be noted that the receiving set suitable for the reception of radio telephone messages is the ordinary damped-wave receiver circuit using a crystal or electron-tube detector. A suitable circuit connection is shown in Fig. 23, which follows the usual type of arrangement with a three-element electron tube *a* as the detector. The capacity of condenser *b* shunting the telephone receivers *c*, should be small so as not to distort the received signal pulsations.

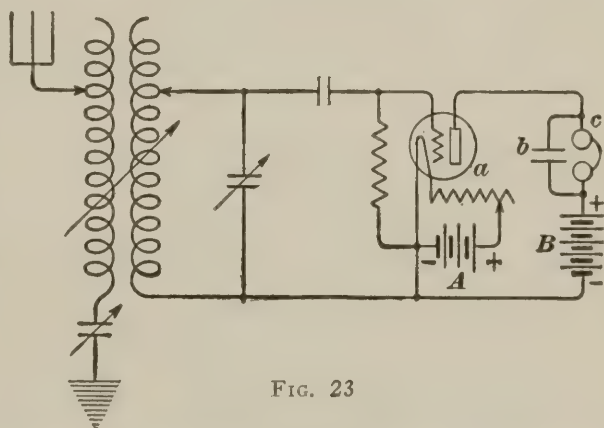


FIG. 23

INDEX

NOTE.—In this volume, each Section is complete in itself and has a number. This number is printed at the top of every page of the Section in the headline opposite the page number, and to distinguish the Section number from the page number, the Section number is preceded by a section mark (§). In order to find a reference, glance along the inside edges of the headlines until the desired Section number is found, then along the page numbers of that Section until the desired page is found. Thus, to find the reference "Air, §6, p7," turn to the Section marked §6, then to page 7 of that Section.